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MILITARY HANDBOOK

SWITCHGEAR AND RELAYING

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ABSTRACT

This handbook contains policy and procedures pertaining to Switchgear and Relaying. It has been prepared as the result of basic design guidance developed from extensive re-evaluation of facilities. It is intended for use by experienced architects and engineers. The contents cover electric switchgear and relaying considerations, such as sources of criteria, medium-, high-, and low-voltage switchgear, distribution equipment, and relaying systems.

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FOREWORD

Change 1, 30 December 1991

This military handbook has been developed from an extensive evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies and the private sector. This handbook was prepared using, to the maximum extent feasible, national professional society, association, and institute standards. Deviations from this criteria, in the planning, engineering, design and construction of naval shore facilities, cannot be made without prior approval of NAVFACENGCOM Code 04.

Design cannot remain static any more than the functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged and should be furnished to Commanding Officer, Naval Facilities Engineering Command, Chesapeake Division, Code 406, Washington Navy Yard, Washington, DC 20374; telephone (202) 433-3314.

THIS HANDBOOK SHALL NOT BE USED AS A REFERENCE DOCUMENT FOR PROCUREMENT OF FACILITIES CONSTRUCTION. IT IS TO BE USED IN THE PURCHASE OF FACILITIES ENGINEERING STUDIES AND DESIGN (FINAL PLANS, SPECIFICATIONS, AND COST ESTIMATES). DO NOT REFERENCE IT IN MILITARY OR FEDERAL SPECIFICATIONS OR OTHER PROCUREMENT DOCUMENTS.

ELECTRICAL ENGINEERING CRITERIA MANUALS
Change 1, 30 December 1991

Criteria Manual	Title	PA
MIL-HDBK-1004/1	Preliminary Design Considerations	CHESDIV
MIL-HDBK-1004/2	Power Distribution Systems	PACDIV
MIL-HDBK-1004/3	Switchgear and Relaying	CHESDIV
MIL-HDBK-1004/4	Electrical Utilization Systems	CHESDIV
DM-4.05	400-Hz Medium-Voltage Conversion and Low-Voltage Utilization Systems	SOUTHDIV
MIL-HDBK-1004/6	Lightning Protection	CHESDIV
MIL-HDBK-1004/7	Wire Communication and Signal Systems	CHESDIV
DM-4.9	Energy Monitoring and Control Systems	ARMY
MIL-HDBK-1004/10	Cathodic Protection	NCEL

MILITARY HANDBOOK
SWITCHGEAR AND RELAYING

TO ALL HOLDERS OF MIL-HDBK-1004/3

1. THE FOLLOWING PAGES OF MIL-HDBK-1004/3 HAVE BEEN REVISED AND SUPERSEDE THE PAGES LISTED:

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v	30 December 1991	v	Reprinted w/o Change
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2. RETAIN THIS NOTICE AND INSERT BEFORE TABLE OF CONTENTS.

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Section 1: SOURCES OF CRITERIA

1.1 Scope. This handbook presents data and considerations necessary for the proper selection of low, medium- and high-voltage switchgear, distribution equipment, and relay systems for control and protection of electric power distribution.

1.2 Cancellation. This handbook cancels and supersedes NAVFAC DM-4.3, Electrical Engineering Switchgear and Relaying, dated December 1979.

Section 2: MEDIUM AND HIGH-VOLTAGE SWITCHGEAR

2.1 Medium and High-Voltage Classes. Table 1 indicates the primary distribution and transmission voltages commonly used. Standard voltages shown without parentheses are preferred.

Table 1
Nominal Voltage Classes[1]

Range	Standard nominal system voltages	Associated nonstandard nominal system voltages
	7.2 kV and under (in kV)	
	(2.4)	2.2, 2.3
	(4.16Y/2.4)	
	4.16	4.
	(4.8)	4.6
	(6.9)	6.6, 7.2
	15-kV class (in kV)	
	(8.32Y/4.8)	11, 11.5
	12Y/6.93	
	12.47Y/7.2	
	13.2Y/7.62	
Medium	(13,8Y/7.970)	
	13.8	14.4
	25-kV class (in kV)	
	(20.78Y/12.)	
	(22.86Y/13.2)	
	(23.)	
	24,94 Y/14.4	
	35-kV class (in kV)	
	34,5Y/19.92	
	(34,5)	33
	Transmission voltages (in kV)	
	(46.2)[2]	
	69[2]	66[2]
	115	110-120
	138	132
High	(161)	154
	230	220

[1]This table abstracted from Institute of Electrical and Electronics Engineers, Inc. (IEEE), IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants,.

[2]American National Standards Institute (ANSI), ANSI C84.1, Voltage Ratings for Electric Power Systems and Equipment (60 Hz), identifies these voltages as higher voltage three-phase systems. IEEE 141 identifies these voltages as medium voltage.

2.2 Circuit-Interrupting Devices. Power fuses in conjunction with load-break switches provide an economical means for circuit and equipment protection and isolation. Current-limiting protectors and power-assisted fuses shall be used to reduce peak fault current for older electrical systems. Circuit breakers shall be used where increased flexibility is required for equipment operation and prompt restoration of service. Reclosers and sectionalizers provide a means of maintaining circuit reliability after a fault occurs. For this reason, they shall be used only when the circuit requires reliability. The maximum interrupting ratings advised for power fuses are indicated in Table 2.

Table 2
Maximum Interrupting Duty for Power Fuses
Ratings of Expulsion-Type Power Fuses

Nominal Rating (kV)	Maximum Continuous Current (A)	Maximum Three-Phase Symmetrical Interrupting Rating (MVA)
7.2	100, 200, 300, 400	162
14.4	100, 200, 300, 400	406
23	100, 200, 300, 400	785
34.5	100, 200, 300, 400	1,174
46	100, 200, 300, 400	1,988
69	100, 200, 300, 400	2,350
115	100, 200,	3,110
138	100, 200,	2,980
161	100, 200,	3,480

Ratings of Current-Limiting Power Fuses

Nominal Rating (kV)	Maximum Continuous Current (A)	Maximum Three-Phase Symmetrical Interrupting Rating (MVA)
2.4	100, 200, 450	155-210
2.4/4.16Y	450	360
4.8	100, 200, 300, 400	310
7.2	100, 200	620
14.4	50, 100, 175, 200	780-2,950
23	50, 100	750-1,740
34.5	40, 80	750-2,600

Table 2 (Continued)
Maximum Interrupting Duty for Power Fuses
Ratings of Solid-Material Boric-Acid Power Fuses

Nominal Rating (kV)	Maximum Continuous Current (A)	Maximum Three-Phase Symmetrical Interrupting Rating (MVA)
2.4	200, 400, 720	155
4.16	200, 400, 720	270
7.2	200, 400, 720	325
14.4	200, 400, 720	620
23	200, 300	750
34.5	100, 200, 300	2,000
46	100, 200, 300	2,000
69	100, 200, 300	2,000
115	100, 250	2,000
138	100, 250	2,000

2.2.1 Circuit Breakers. In the selection of circuit breakers, ratings conforming to ANSI C37.06, Preferred Ratings and Related Required Capabilities for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis. and IEEE C37.04, American National Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, shall be implemented.

2.2.1.1 Voltage Rating. The voltage rating will be determined in terms of three-phase, line-to-line voltage:

a) Maximum nominal system voltage for which the breaker is intended, and
b) Maximum operating voltage at which the breaker will be used, taking into consideration line voltage regulation, machine overexcitation and overspeed, and shunt capacitance.

2.2.1.2 Insulation Level Rated Impulse Withstand Voltage. Referring to IEEE C37.04, the impulse strength of the breaker must be coordinated with the surge protection of the system as follows:

a) Across breaker contacts, and
b) Between breaker contacts and ground. No increase shall be indicated in surge voltage as a result of voltage reflection.

2.2.1.3 Frequency. For a frequency of 60 Hz, compare the calculated ratings with standard ratings. For other frequencies, check with the manufacturer(s).

2.2.1.4 Continuous Current. Calculate the maximum current flow through the breaker by computing the current flow under normal and contingency conditions. Provide for future load growth, if required.

2.2.1.5 Interrupting Duty. To select the proper interrupting duty using IEEE C37.010, Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, it is necessary to perform a complete fault analysis to determine the required interrupting duty of the circuit breaker under normal and contingency conditions. Use the criteria in Westinghouse, Electrical Transmission and Distribution Reference Book, and the following:

a) Provide for a future system design that might materially affect the interrupting duty of the circuit breaker. Circuit breakers are rated on a symmetrical basis rather than on an asymmetrical (total current) basis, and application shall follow requirements of IEEE C37.010, and IEEE C37.011, Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

b) If the operating voltage of the circuit differs from the rated voltage of the circuit breaker, correct the final values to correspond with the rated values given in the manufacturer's circuit breaker rating tables;

c) Determine the asymmetrical requirements based on the breaker contact parting time; and

d) Determine the actual operating duty and interruption time of the breaker from the relay setting calculations (refer to Section 4).

2.2.1.6 Altitude Correction. Correction for voltage and current ratings are required for altitudes above 3,300 ft (1,000 m). Use IEEE C37.20, Switchgear Assemblies Including Metal-Enclosed Bus, and National Electrical Manufacturers Association (NEMA), NEMA SG-4, Alternating-Current High-Voltage Power Circuit Breakers, for correction factors.

2.2.1.7 Ambient Temperature. Circuit breakers in environments with ambient temperatures higher than +104 deg. F (40 deg. C) or lower than -22 deg. F (-30 deg. C) shall be derated in conformance with IEEE C37.010.

2.2.1.8 Breaker Selection. Breaker selection will be conducted using the following criteria:

a) Factor Evaluation. The evaluation of the voltage rating, insulation withstand voltage rating, frequency, continuous current, and interrupting duty provides the required rating of the circuit breaker. For the final selection, select circuit breakers that meet the required rating at the lowest original and maintenance cost and at the lowest fire hazard cost.

b) Selection Guide. Refer to Table 3 for circuit breaker characteristics.

Table 3
Characteristics of Circuit Breakers

Voltage range	Application
Medium (1.5 kV to 34.5 kV)	1.5 through 15.0-kV up to 1,000-MVA interrupting duty. Vacuum circuit breakers shall be used. Provide suitable enclosure. Consider use of overhead/outdoor/open style sub/switch station. Consider use of sulphur hexafluoride (SF_6) and mineral oil circuit breakers. 15.0 through 34.5-kV up to 2,500-MVA interrupting duty. Allow use of vacuum circuit breakers where they provide adequate interrupting duty. Permit use of air blast (compressed-air type), sulphur hexafluoride (SF_6), and mineral oil or oil circuit breakers as a contractor's option. Use oil circuit breakers where adverse atmospheric conditions occur
Medium and high (above 34.5 kV)	Use oil circuit breakers, grounded metal-tank type with pneumatic operating mechanisms. For voltages of 115 kV and above, permit use of sulphur hexafluoride (SF_6) or mineral oil-operated types as a contractor's option.

2.2.2 Reclosers and Sectionalizers

2.2.2.1 Application. Automatic reclosing shall be used for system configurations such as overhead lines serving residential or commercial loads. With other system configurations, reclosing may cause problems. Select the location where these reclosers are to be installed, giving due consideration to the line to be protected. The location shall be limited to a value where the current, for a fault at the remote end of the line to be protected, is equal to at least 1-1/2 times the minimum trip of the recloser. The minimum trip value of a recloser is usually about twice the coil rating (refer to Standard Handbook for Electrical Engineers, Donald G. Fink and H. Wayne Beaty. Use subsection entitled Overcurrent Protection). Coordinate the recloser with the existing protection equipment by comparing the recloser times with the current time curves of the existing equipment. Select the automatic recloser to be used by following essentially the same procedure outlined for a circuit breaker.

2.2.2.2 Radial Feeder System. Determine whether the relay protection at the substation will operate for faults at the remote ends of the feeder. Check whether successful reclosure is probable in the event of a tripout. On bare overhead lines, the probability of a reclosure is good; on underground or aerial cable, the probability is not as good. Investigate the problems that may occur with existing protection (fuses, relays, and medium-voltage taps).

2.2.2.3 Tie Feeder System. For tie feeder systems, apply the same factors as described for the radial feeder system (refer to para. 2.2.3.1). Determine whether it would be desirable to insert reclosers in the main run between substations when the total circuit load can be supplied from either substation. The circuits from each substation must have the same phase rotation. The circuit breakers feeding from each substation must coordinate with the recloser.

2.2.3 Power Fuses. Power fuses shall be used where the system configuration (refer to paras. 2.2.3.1 and 2.2.3.2) indicates that it would be advantageous. Do not use power fuses for circuits requiring reclosing.

2.2.3.1 Radial Feeder System. Determine whether relay protection is needed, in addition to fuses, to provide for faults both at the substation and at the remote ends of the feeder. If relay protection is provided, it will be necessary to use circuit breakers. Check the type of load on the feeder to determine if isolation resulting from a blown fuse would cause damage to utilization equipment, such as single phasing of the three-phase equipment or relatively long outage time. If it is determined that the use of fuses would result in damage to utilization equipment, use either circuit breakers or fuses in combination with phase-loss protection on the equipment to provide protection for that equipment. Investigate the problems that may occur with existing protection.

2.2.3.2 Tie Feeder System. Do not install fuses in the main run of feeders interconnecting two substations. Fuses may be installed on spurs of tie feeders. Where the installation of fuses is desirable, the fuse location, rating, and coordination need to be determined (refer to Standard Handbook for Electrical Engineers, Donald G. Fink and H. Wayne Beaty). Specify a fuse of the required rating and select a fuse from these basic types: open-fusible link, expulsion, boric acid, and current limiting. Selectivity or coordination shall be considered in determining fuse selection.

2.2.4 Load-Break Switches. Factors necessary to the selection of load-break switches are duty, rating and operation.

2.2.4.1 Duty. Types of current to be interrupted are, for example, capacitive, magnetizing, and load (resistive and inductive).

2.2.4.2 Rating. Switch rating with respect to voltage, continuous current, frequency, and insulation level as outlined for circuit breakers in para. 2.2.1 of this section.

2.2.4.3 Operation. Electrical versus manual.

2.2.4.4 Arc Interruption. Load-break or interrupter switches are available in many different mechanical designs to provide arc-breaking capacity. Designs include the "snap-open" type with a small measure of interrupting ability, the "puffer" or "de-ion" and the oil-insulated types for greater interrupting ability, and the "SFÚ6¿", or "vacuum" types for interruption of high-voltage circuits. Caution must be exercised in selecting oil switches to ensure that the short-circuit duty is adequate.

2.2.4.5 Mounting. Select load-brake switches from types suitable for pole mounting, ground mounting, or those provided in a switchgear lineup. Except where oil is more suitable, use only nonoil type. Transmission system voltages may require the use of bus and switch structure-mounted types.

2.3 Circuit-Isolating Devices. The location of circuit-isolating devices depends on the system configuration.

2.3.1 Locations. Factors to be considered with respect to advantageous locations stated in paras. 2.3.1.1 and 2.3.1.2.

2.3.1.1 Service Continuity. Provide for isolation of faulted sections of a feeder so that service may be restored to the unfaulted sections of the feeder.

2.3.1.2 Maintenance. Provide for isolation of equipment from the rest of the system so that periodic maintenance on this equipment may be performed safely with as little associated equipment out of service as possible.

2.3.2 Rating. The isolating devices are not intended to break load; however, their rating must be determined with respect to voltage, insulation level, frequency, continuous current, and fault current.

2.3.3 Types. The type of isolating device to be used may be disconnect switches or disconnecting links.

2.3.4 Selection. Select the actual switch or fuse link to be used by reviewing the appropriate manufacturers' catalogs and choosing a unit that meets the required rating.

2.4 Protection Devices. The extent of surge study and traveling wave data required will depend on the complexity and size of the system. Normally, this data is only required for systems of 20-Megavolt Amperes (MVA) or larger. A computer study may be necessary for systems of that magnitude or for those with two or more sources of power and complex interconnecting lines. Short extensions to existing systems shall usually be based on data already compiled.

2.4.1 Surge Study. The selection of protective devices shall be made after investigating the determining factors affected by lightning and switching surges. Use criteria in ANSI C62.2, Guide for the Application of Valve-Type Lightning Arresters for AC Systems; IEEE 399, Recommended Practice for Industrial and Commercial Power System Analysis; and Westinghouse, Electrical Transmission and Distribution Reference Book. Factors that must be considered are described in paras. 2.4.1.1 through 2.4.1.7.

2.4.1.1 System Configuration. Include the effect of multiple transformers, lines, and circuit breakers and the effect of electrostatic and electromagnetic coupling between circuits where available and economically feasible.

2.4.1.2 Atmospheric Conditions. Temperature, pressure, and humidity shall be considered in choosing the type of protective device to be used.

2.4.1.3 Basic Impulse Insulation Level. Determine the basic impulse insulation level of system equipment as well as that of the protective equipment in use.

2.4.1.4 Types of System Grounding. System grounding includes the isolated, neutral, and effectively grounded types (refer to MIL-HDBK-1004/1, Preliminary Design Considerations, and IEEE 142, Recommended Practice for Grounding Industrial and Commercial Power Systems, for systems grounding criteria).

2.4.1.5 Station Shielding. Station shielding is determined by the number of ground wires, ground mat or counterpoise details, tower footing resistance, location of surge arresters, and associated protective equipment (refer to IEEE 80, Guide for Safety in Substation Grounding, and IEEE 81, Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System).

2.4.1.6 System Voltage. Some of the factors affecting the selection of protective devices include normal voltage, rated voltage for continuous operation, and maximum voltage that the system insulation must withstand.

2.4.1.7 Past Performance. Ascertain the performance elsewhere of this type of system against lightning and switching surges.

2.4.2 Traveling Waves. Determine the magnitudes and shapes of traveling waves that may occur on the system as a result of a surge impulse. The procedures are described in paras. 2.4.2.1 through 2.4.2.5 of this section.

2.4.2.1 Surge Impedance. Compute the values of surge impedance at strategic locations on the system.

2.4.2.2 Reflection and Refraction Constants. Calculate the reflection and refraction constants at the junctions of equipment having different surge impedance values.

2.4.2.3 Equipment Resistance. Determine the attenuation of the equipment resistance on a traveling wave.

2.4.2.4 Natural Frequency. Determine the natural frequency at which the traveling wave will propagate.

2.4.2.5 Lattice Network. With the aforementioned information, construct a lattice network and compute the values of voltage at the various surge impulse points on the system. An example of a lattice network is given in the Westinghouse, Electrical Transmission and distribution Reference Book.

2.4.3 Equipment Selection. Select equipment with respect to the advantages and limitations of the different types that may be used to protect the system from surges. The characteristics of the selected equipment must be related to protective level, tolerances, operating life, and effects on system relaying and fuses.

2.4.3.1 Arresters. Arresters are the preferred method of surge protection. (Refer to MIL-HDBK-1004/2, Power Distribution Systems, for characteristics and applications of arresters.)

2.4.3.2 Gaps. Characteristics of rod and sphere types of protective gaps are that they:

a) not be capable of interrupting power flow current,
b) are relatively large,
c) are affected by surrounding bodies and weather, and
d) have large tolerance in withstand-time curve.

2.4.4 Coordination. The insulation level of the protective equipment must be coordinated with the insulation level of the system equipment. Refer to IEEE 142 and perform the following:

a) Protective Voltage Level. Establish a protective voltage level to correlate with the system voltage level at which protective equipment (such as surge arresters) is expected to operate.

b) Level of Insulation of System. Determine the level of insulation of the system equipment.

c) Atmospheric Conditions. Check the effect of atmospheric conditions on the flashover characteristics of the equipment insulation.

d) Arrester Separation. Determine the effect of arrester separation from the equipment to be protected. This separation shall be kept to a minimum.

e) Volt-Time Withstand Characteristics. Compare volt-time withstand characteristics of the system equipment insulation with the volt-time withstand characteristics of the protective equipment.

f) Margin Between Levels. Determine the margin between the protective voltage levels and equipment withstand voltage.

3.1 Circuit-interrupting Devices. Specify low-voltage equipment to meet atmospheric conditions or climatic requirements.

3.1.1 Circuit Breakers. Circuit breakers are preferred since they cannot single phase, do no require fuse replacement, and are more difficult to modify for carrying currents greater than originally intended. Circuit breakers rather than fusible switches shall be used for circuit protection, except for special applications, such as critical technical load panelboards (refer to MIL-HDBK-1004/1). In the selection of circuit breakers, refer to paras. 3.1.1.1 through 3.1.1.5.

3.1.1.1 Voltage Rating. Determine the maximum operating voltage at which the breaker will be used.

3.1.1.2 Frequency. Determine the breaker rating at the frequency to which it will be applied. Standard frequency is 60 Hz. When used for other frequencies, such as 50 or 400 Hz., the manufacturer shall be consulted for a derating factor. Most manufacturers do not derate when frequencies are at 50 Hz.

3.1.1.3 Continuous Current. Compute the maximum continuous current flow through the breaker for normal and contingency conditions. Also consider provisions for future load growth, where required.

3.1.1.4 Interrupting Duty. A complete fault analysis may be necessary to select the proper circuit breaker interrupting duty under normal and contingency conditions. Use criteria in IEEE 242, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, and IEEE 141. In cases where there is less than 25-percent motor load, fault current calculations by the simplified graphic method (refer to Appendix A) are sufficiently accurate. Determine if provisions for future system design will affect the interrupting duty of the circuit breakers. Cascading is not permitted, except as covered in Section 4 of this handbook. NAVFAC computer programs available for calculating fault currents include Computer-Assisted Power System Engineering (CAPSE) and VICTOR.

3.1.1.5 Breaker Selection. Of the breakers described in a) through e), specify breakers of the required rating with due consideration of initial cost, maintenance, and similar items (refer to MIL-HDBK-1004/2):

a) Molded-Case Circuit Breakers. Molded-case circuit breakers shall be used for normal duty only. This type of circuit breaker is generally equipped with noninterchangeable-thermal and adjustable-magnetic or solid-state trip elements. Interchangeable trip elements are available from circuit breakers of more than 225 A frame size. Current-limiting breakers are available in most sizes. Molded-case circuit breakers are suitable for mounting in panelboards and switchboards. Derate thermal tripping setting, depending on ambient temperature (refer to NEMA AB-1, Molded Case Circuit Breakers, and National Fire Protection Association (NFPA), NFPA-70, National Electrical Code).

b) Integrally Fused Molded-Case Circuit Breakers. Integrally fused, molded-case circuit breakers shall be used to protect small loads connected to systems with high available short-circuit currents. Various current-limiting fuses are available.

c) Power Circuit Breakers. Power circuit breakers shall be used in accordance with IEEE 242. For low-voltage AC power circuit breakers used in enclosures, refer to the application guide in IEEE C37.13, Low-Voltage AC Power Circuit Breakers Used in Enclosures.

d) Current-Limiting Circuit Breakers. Current-limiting circuit breakers are used in lieu of current-limiting fuses only where economically feasible. Current-limiting circuit breakers are defined in Underwriters Laboratories, Inc., (UL), UL 489, Molded-Case Circuit Breakers and Circuit Breaker Enclosures.

e) Insulated-Case Circuit Breakers. Insulated-case circuit breakers shall be used to the maximum extent feasible in lieu of more expensive open-type air circuit breakers. Insulated-case circuit breakers shall conform to NAVFACENGCOM Guide Specification (NFGS) NFGS-16312, Low-Voltage Switchgear and Secondary Unit Substations or NFGS-16462, Pad-Mounted Transformers (75 kVA to 500 kVA).

3.1.2 Switches. Generally, use switches only where necessary for isolation purposes. Switches for Heating, Ventilating, and Air-Conditioning (HVAC) systems must be installed in conformance with NFPA-70.

3.1.2.1 Enclosures. Select enclosures of electrical equipment according to NEMA-type designations to ensure safe and reliable operation for the applicable external conditions (refer to NEMA ISC6 Series, Enclosures for Industrial Controls and Systems).

3.1.2.2 Switch Duty. Switch equipment duty is defined by NEMA KS-1, Enclosed Switches. Use general-duty equipment for nonessential applications and where equipment is subject to infrequent operation. General duty equipment is intended for use on circuits of 240 V or less; therefore, heavy-duty equipment is required for higher voltages. Use heavy-duty equipment for industrial application where reliability and continuity of service are prime factors and where equipment is subject to frequent operation. It is intended for use on circuits of 600 V or less and where available fault current of more than 10,000 amperes are likely to be encountered.

3.1.2.3 Rating. To determine ratings, follow the basic procedure outlined for circuit breakers in para. 3.1.1. Motor disconnect switches shall have an ampere rating of at least 115 percent of the full-load current rating of the motor to meet the requirements of NFPA-70; however, 125-percent capacity is not considered excessive.

3.1.2.4 Fusible Switches. Fusible switches combine isolation with protection of a particular component of the circuit.

3.1.2.5 Selection. Specify a switch of the appropriate rating and enclosure (refer to NFPA-70 and NEMA KS-1) and select from the following:

a) Safety (disconnect) switches can be fused or nonfused units operable up to 600 volts and 1,200 amperes of maximum continuous current and are normally used for motor isolation or protection.

b) Other switches such as heavy-duty switches operable up to 600 volts and 1,200 amperes of continuous current and load-break pressure switches operable up to 600 volts and 5,000 amperes of continuous current shall only be used for application where circuit breakers are not appropriate.

3.1.2.6 Transfer Switches. Automatic transfer (and bypass/isolation) switches shall conform to NFGS-16262, Automatic Transfer (and Bypass/Isolation) Switches.

3.1.3 Fuses. Generally fuses will be used only when required to provide adequate interrupting duty for short-circuit conditions.

3.1.3.1 Rating. Determine the rating of fuses based on voltage, current-carrying capacity, and interrupting requirements. Take into consideration motor-starting and other forms of inrush current.

3.1.3.2 Coordination. Fuses shall be coordinated with all other circuit protective equipment that operates in series with them in the system. Use the time-current curves of devices.

3.1.3.3 Selection. Specify a set of fuses of the calculated rating; select fuses from Table 4. The 10,000-ampere interrupting capacity shall only be used for critical technical-load panelboards where circuit breakers are not permitted. Higher interrupting capacities are usually used in conjunction with circuit breakers.

3.1.4 Protection. Protection devices shall be selectively coordinated to provide maximum system reliability.

3.1.4.1 Service-Entrance Protection. Service-entrance protection shall consist of a nonautomatic load interrupter with a current limiter for services with high available short-circuit currents.

3.1.4.2 Network Protectors. Use network protectors to prevent damage in network transformers. Specify associated reverse-current relays which are sufficiently sensitive to trip the main breaker upon loss of transformer magnetizing current (refer to NEMA SG-3, Low-Voltage Power Circuit Breakers, and Section 4 of this handbook).

Table 4
Fuse Selection

Type	Maximum continuous current amperes	Interrupting capacity amperes
Single element.......	600	10,000
Dual element:		
Low interrupting capacity.........	600	10,000
High interrupting capacity.........	600	100,000
Current limiting....	600	200,000
Current limiting....	6,000	200,000

3.1.4.3 Low-Voltage Ground-Fault Protection. NFPA-70 requires ground-fault protection at the service disconnecting means for circuits rated 1,000 amperes or more and for circuits having a voltage-to-ground in excess of 150 volts. Where such protection is required, current transformers connected in residual or a zero sequence current transformer shall be applied as shown in Figure 1. The use of a single current transformer on the grounding electrode conductor is not acceptable because grounding of the service transformer provides a second point of ground-fault current which is not sensed when this system is used.

3.1.4.4 Surge Protection. Provide arresters and metal-oxide varistors as required by the equipment being protected (refer to MIL-HDBK-1004/2 and MIL-HDBK-419, Grounding, Bonding, and Shielding for Electronic Equipments and Facilities).

3.2 Grouped Devices. Switchboards, power distribution panelboards, and branch-circuit panelboards are included and shall be provided spare capacity for normal load growth.

3.2.1 Switchboards. Place switchboards as close as possible to the center of the load to be served. Select utility areas and avoid locations near heat-dissipating equipment.

3.2.1.1 Clearances. Follow the procedure outlined for indoor unit substations in MIL-HDBK-1004/2 and NFPA-70.

3.2.1.2 Spare Capacity. Provide 25-percent additional spare empty compartments for future circuit-interrupting devices, only where the nature of the project indicates the necessity, and 25-percent spare bus capacity.

3.2.2 Power Distribution Panelboards. In general, panelboards serving three-phase motors and power equipment shall be of the circuit breaker type.

3.2.2.1 Mounting. Use wall-mounted panelboards where possible; otherwise, adopt a freestanding type.

3.2.2.2 Location. Place the power and distribution panelboard as near as possible to the center of the load.

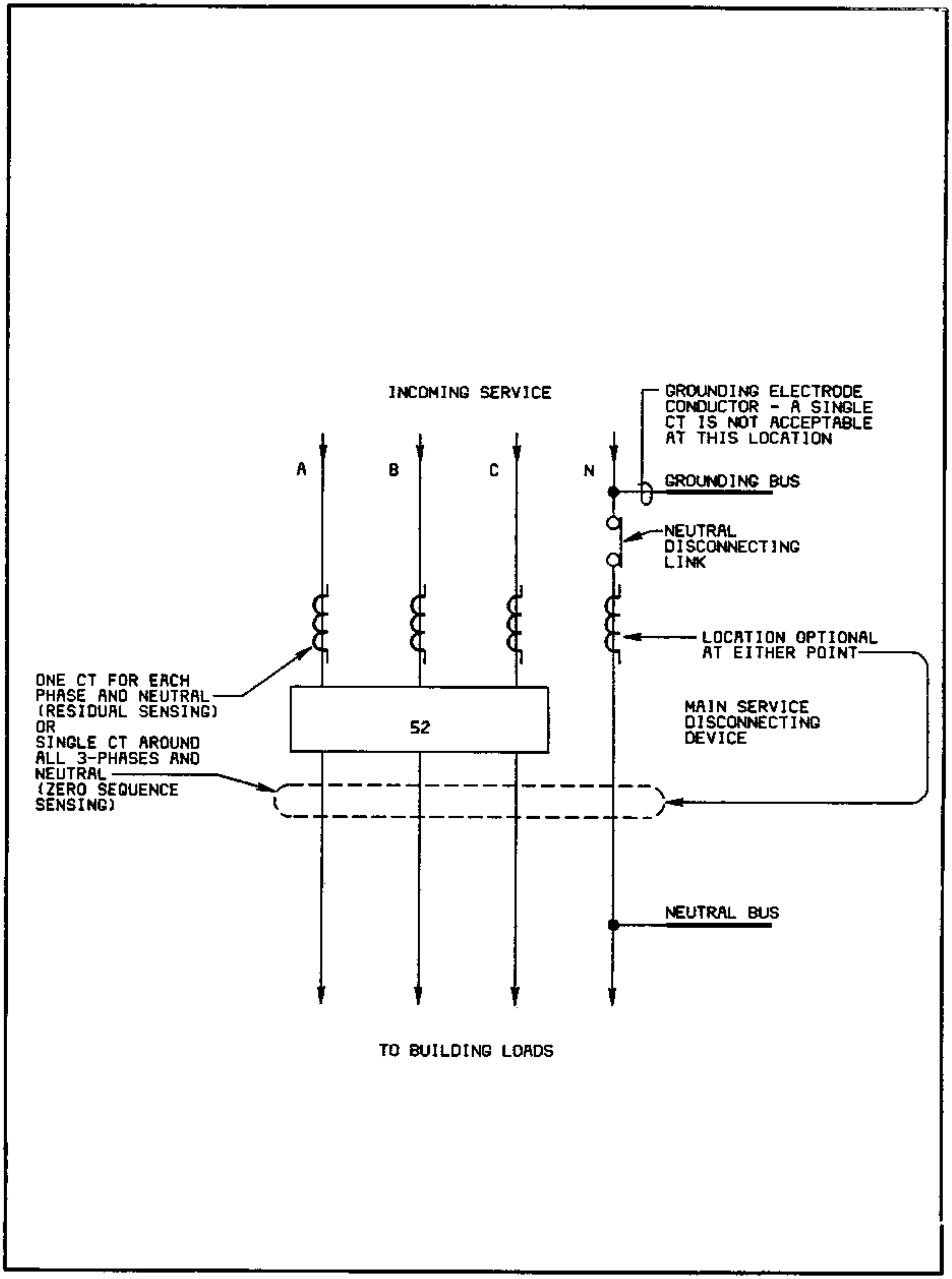


Figure 1
Low-Voltage Ground-Fault Protection

3.2.2.3 Limitations. In establishing design limitations, consider the maximum height of the upper breaker, the maximum number of breakers in one panelboard, the maximum capacity of the lugs, and the maximum capacity of the mains. Normally, panelboards with more than two lugs per phase shall not be used. Where more than 1,200-ampere mains are used, switchboard construction shall be provided.

3.2.2.4 Spare Capacity. A spare bus capacity of 25-percent shall be provided, 20-percent spare circuit breakers, and 5-percent spare empty spaces as a minimum.

3.2.3 Branch-Circuit Panelboards. Branch protective devices in panelboards shall be circuit breakers unless fuses are required because of available fault currents or limitations on critical load outage times. Consider the difficulty of stocking fuses at remote installations.

3.2.3.1 Location. Panelboards shall be located as near as possible to the center of the load. For panelboards serving one type of load, sacrifice ease of accessibility when large-scale economy of branch circuits is possible. However, do not provide an installation which would necessitate a reconnaissance mission to locate the panelboard.

3.2.3.2 Main Circuit Breaker. Main circuit breakers shall be used for isolation purposes and for short-circuit protection (refer to NFPA-70). Main circuit breakers must be UL listed as suitable for service-entrance use.

3.2.3.3 Limitations. Limitations shall be the same as those for power distribution panelboards.

3.2.3.4 Spare Capacity. The spare capacity shall be the same as that for power distribution panelboards.

3.3 Busways. Busways shall be used to carry large current loads through minimum physical space and for system flexibility (refer to NEMA BU-1, Busways, and UL 857, Electric Busways and Associated Fittings).

3.3.1 Rating. The ratings of busways shall be used on maximum current under normal and contingency conditions.

3.3.2 Duty. Determine maximum symmetrical short-circuit current available at the connecting point of the bus duct. Specify bracing to withstand mechanical stresses produced by such current.

3.3.3 Voltage Drop. Voltage drops shall not exceed the limits imposed by NFPA-70.

3.3.4 Selection

3.3.4.1 Feeder Busway. Feeder busways shall be used to supply heavy loads to panelboards, with minimum losses and voltage drops. Specify low-impedance busways.

3.3.4.2 High-Impedance Busway. High-impedance busways can be used to reduce short-circuit duty of switchboard equipment connected at the busway load end, but such use is not recommended because of energy losses; current-limiting fuses or circuit breakers with higher interrupting duties shall be used instead.

3.3.4.3 Plug-In Busway. Plug-in busways shall be used for multiple tapping and for system flexibility.

3.3.4.4 High-Frequency Busway. High-frequency busways shall be used where the system frequency is 180 Hz and above.

3.3.4.5 Trolley Duct. Trolley ducts shall be used for supply of overhead cranes, hoists, and moving loads in general and for industrial lighting.

3.4 System Corrective Equipment. System corrective equipment includes voltage regulators and capacitors. This equipment shall comply with the criteria in paras. 3.4.1 and 3.4.20.

3.4.1 Voltage Regulation. Voltage regulators shall be used to maintain a constant load voltage from the available source or a constant utilization voltage with a variable load on a weak source of supply (refer to ANSI C57 Series, Transformers). The regulator kVA can be calculated by multiplying the line current by the rated range of regulation in kilovolts or by multiplying the line current times the line kilovolts times the per unit regulation (percent regulation in decimal equivalent). When using single-phase regulators to serve three-phase loads, provide regulators connected in a grounded wye, ungrounded delta, or ungrounded open-delta configuration.

3.4.2 Power Factor. Capacitors shall be used to correct the low power factor. An overall load power factor of not less than 90 percent shall be achieved. When power factor correction capacitors have been installed and the calculated power factor exceeds 95 percent, switched capacitor banks shall be used to prevent overvoltages during off-peak hours. Capacitors on inductive loads shall be provided as near to the loads as is practical. Capacitors for large inductive loads shall be switches that are simultaneous with the load. Install capacitors close to the loads to reduce reactive current through feeders, improve voltage regulation, and reduce losses (refer to Standard Handbook for Electrical Engineers, Donald G. Fink and H. Wayne Beaty, subsection entitled Power Distribution and subsection entitled Application of Capacitors).

3.5 Current-Converting Equipment. If rectifiers are to be used, determine the rectifier duty and select from the types described in paras. 3.5.1 through 3.5.4.

3.5.1 Silicon-Controlled Rectifiers. Silicon-Controlled Rectifiers (SCRs) or thyristors shall be used where high efficiency and accurate voltage control are required. This type is suitable for practically all load ranges.

3.5.2 Grid-Controlled (Mercury-Arc) Rectifiers. Where accurate voltage control is required, grid-controlled rectifiers shall be used that are capable of carrying medium to heavy loads.

3.5.3 Metallic Rectifiers. Metallic rectifiers shall be used for small loads, battery charging, and similar purposes.

3.5.4 Rotating Equipment. Rotating equipment is the least efficient method of rectifying. The use of large flywheels on rotating equipment to supply greater amounts of energy for short periods of time is not permitted.

3.6 Metering. All building service-entrance equipment, such as main distribution switchboards or main distribution panelboards, shall be equipped with a voltmeter, ammeter, kW meter, kVAR or power factor meter, and kWh meter with peak demand register and pulse generator for future connection to energy monitoring and control systems.

Section 4: RELAYING

4.1 Introduction. The purpose of relaying is to remove faulted circuits from a system as quickly as possible by operating circuit breakers. Considerations as to appropriate operation must take into account system stability, possible apparatus damage, continuity of supply to other portions of the system, and rapid reestablishment of service. Time for relay operation would ideally be instantaneous; however, since coordination with other protective zones is required, such selectivity requires some sacrifice of speed. Protective relaying schemes shall be as simple as is compatible with satisfactory operation of equipment. Unless otherwise indicated, protective relaying is to be provided only for high- or medium-voltage systems. For further details, consult Westinghouse, Applied Protective Relaying; The Art and Science of Protective Relaying, C. Russell Mason; and IEEE 242.

Requirements for relaying systems shall be as described in paras. 4.2 through 4.9.

4.2 Fault Study. The extent of short-circuit computations will depend upon the complexity of the system. Radial distribution from a single power source usually requires coordination based on maximum short-circuit duties which will be approximately that of the supplying substation bus. A more complex system, such as one with two or more sources of power and interconnecting lines, may require a computer study. Among the data produced shall be phase and ground-fault currents for both source and end-of-line faults under all operating conditions. A program known as CAPSE is available from the utilities branch of each NAVFACENGCOM division. This program can be used for determining faults under steady-state load flows. A suitable substitute may be found among commercially available software and documentation.

4.3 Fault Detection. Relaying systems shall be able to detect faults in circuits or apparatus under all normal operating arrangements and for all types of faults. Complete protection may not always be possible because of coordination or selectivity requirements. Also, complete selectivity or coordination may not be possible either. The optimum protective device system is based on both protection and coordination requirements. An example is the coordination of circuit breakers and fuses. In some cases, the inherent reliability of the equipment does not justify the costs of extra protection.

4.4 Selectivity. In the design of a selective protective relaying system, the conditions in paras. 4.4.1 through 4.4.3 must be met.

4.4.1 Minimum Disturbance of System. Only the faulted circuit or apparatus shall be disconnected, with a minimum disruption of the system.

4.4.2 Remote Backup. Line relays shall be coordinated with relays of adjoining zones, which are set to clear a fault in the next zone, only if the primary relays at the next substation have failed to clear the fault. Many relaying installations have an inherent backup feature and do not require separate backup protection, for example, time overcurrent and certain forms of differential relaying. In some situations, such as pilot-wire relaying, local backup relays may be required.

4.4.3 Discrimination. Relays must distinguish between faults and normal load conditions (for example, cold load pickup, motor-starting current, and transformer inrush). The normal load condition may exceed the continuous load of the circuit, but this is anticipated. The protective relaying can be coordinated to prevent nuisance tripping.

4.5 Overlapping of Protective Zones. Current transformers shall provide overlapping of protective zones at each circuit breaker.

4.6 Coordination with Utility Company. Wherever the relaying system involves a utility company network, the protective relaying scheme shall be coordinated with the utility company.

4.7 Adaptability to Future Expansion. Adaptability of the relaying scheme to future expansion of the system must be provided. Relays shall be of the "drawout" type, with the relay mechanism in a cradle for easy removal. Shorting bars must be provided to short any current transformer circuits when the cradle is removed. Induction disc relays are generally preferred. During a fault, the reset action of an induction disc relay follows the thermal reset action of the load (for example, conductors, transformers, and motors) and provides incremental operation of the relay until tripping occurs. When relays are specified, an investigation shall be made to determine that the relay type being specified is not scheduled for obsolescence. Solid-state relays may be considered due to the industry trend towards manufacture of solid-state relays. However, caution shall be exercised as use of fast-resetting solid-state relays will not provide reliable circuit protection.

4.8 Method of Tripping Circuit Breakers. Batteries shall be used for closing and tripping circuit breakers. Standardize on 125 Vdc direct current for most central station installations. Use 48 Vdc direct current only where necessary. Batteries are inherently reliable devices, and justification is necessary if more than one battery system is provided at any location. Remoteness of an area is not considered justification for installing a backup battery system; at remote locations, failure usually results from inadequate maintenance. Most uninterruptible power systems operate on only one battery system. Closing shall be by a stored energy mechanism. For extremely small installations where battery cost is not justified, alternating current may be used for closing and tripping. If adequate current is always available during fault conditions, current transformers or a protected circuit provide a reliable source. Capacitor tripping may also be utilized. Relay contacts shall not break the shunt-trip current; breaking shall be done by auxiliary switches. Provide a red pilot indicating light to supervise, the shunt-trip circuit. Use hand-reset lockout relays for multiple tripping arrangements.

4.9 Instrument Transformers. Burdens and accuracy classes shall be adequate for the metering and relay devices supplied. Excessive secondary lead length shall be avoided. Ratio error may have an effect on differential relaying.

4.9.1 Current Transformers. The use of multiratio current transformers is encouraged.

4.9.2 Potential Transformers (PTs). Resistive-type PTs are generally used for single-function burdens of less than 36 VA. For multiple-burden applications and burdens above 36 VA, use capacitive coupling-type PTs.

4.10 Device Numbers and Functions

4.10.1 System. The devices used in switching equipment are referred to by numbers, with appropriate suffix letters when necessary, according to the functions they perform. Use numbers for devices based on the system adopted as standard for switchgear by IEEE. A list of standard device function numbers is provided in Appendix B. For detailed descriptions, refer to IEEE C37.2, Standard Electrical Power System Device Function Numbers. This system is used in switchgear connection diagrams, in relay instruction books, and in specifications.

4.10.2 Commonly Used Relay Device Numbers. Commonly used relays are described in Table 5 along with their general applications.

Table 5
Commonly Used Relays

Device No.	Function	General application line					
		Phase fault	Ground fault	Bus	Transformer	Generator or motor	Load shedding
21	Distance...........	X	X				
25	Synchronizing or sync check.........					X	
27	Undervoltage					X	
32	Directional power...					X	
49	Machine or transformer thermal relay.............				X	X	
50	Instantaneous overcurrent........	X	X	X	X	X	
51	AC time overcurrent............	X	X	X	X	X	
63	Liquid or gas pressure, level or flow...........				X		
67	AC directional overcurrent........	X	X				
81	Frequency..........					X	X
85	Carrier or pilot wire receiver......	X	X				
87	Differential........	X	X	X	X	X	

4.11 Relaying of Distribution Lines. Distribution lines have voltages of 34.5 kV and below. They are generally run for relatively short distances, 3 to 10 miles (5 to 15 km) at Naval facilities.

4.11.1 Overcurrent Relaying. Use overcurrent relays of the nondirectional type (51/50, 51N/50N) for radial circuits where power can flow in only one direction (the suffix letter "N" denotes device connected in neutral line (see Figure 2).

4.11.1.1 Types of Relays. Instantaneous (50, 50N) and time-overcurrent (51, 51N) relays with various time characteristics are available. Time-overcurrent relays shall always be specified with the instantaneous attachment, whether used or not, to provide for future load or system changes. The types of relays to be used are as follows:

a) Instantaneous overcurrent (50, 50N) relays, using plunger-type relays, shall be used only in conjunction with time-overcurrent relaying. Instantaneous relays must be adjusted so they will not operate on faults in an adjoining protective zone.

b) Inverse time (51, 51N) relays have a relatively flat time-current characteristic. They are more difficult to coordinate with other relays than are the very-inverse type. The universe time relays shall generally be limited to locations where there are no coordination requirements with other relays. They are mainly used for motor protection.

c) Very-inverse time (51, 51N) relays give a shorter tripping time than the inverse time relays. For low-level faults, however, the tripping is longer. The very-inverse time characteristic is generally used more than any other to relay distribution and subtransmission lines.

d) Extremely inverse time (51, 51N) relays shall be used only in special circumstances, such as where close coordination with the much steeper time-current characteristics of the medium-voltage fuses is required or where energizing a circuit may cause a heavy inrush current.

4.11.1.2 Mixing Time Characteristics. In general, mixing relays of different time characteristics shall be avoided because selectivity is thereby impaired. To ensure proper selectivity, the time interval (coordinating time) between the operation of an overcurrent relay and the next relay up the line shall be approximately 0.2 to 0.3 seconds. This margin is determined at the value of current sensed by each device for a single fault.

4.11.1.3 Settings. Relay settings shall be based on a relay coordination study.

4.11.1.4 Usual Connections. Overcurrent phase relaying shall always include relaying of ground-fault current by interposing a neutral relay in the residual connection of current transformers in addition to the phase relays, as shown in Figure 2.

4.11.2 Directional Overcurrent Relaying. Use overcurrent relays of the directional type (67, 67N) for loop feeders where power normally flows in either direction and where power can flow back from other power sources such as large synchronous motors. Consider provision of a current polarizing option if the available voltage source is unreliable as a polarizing source.

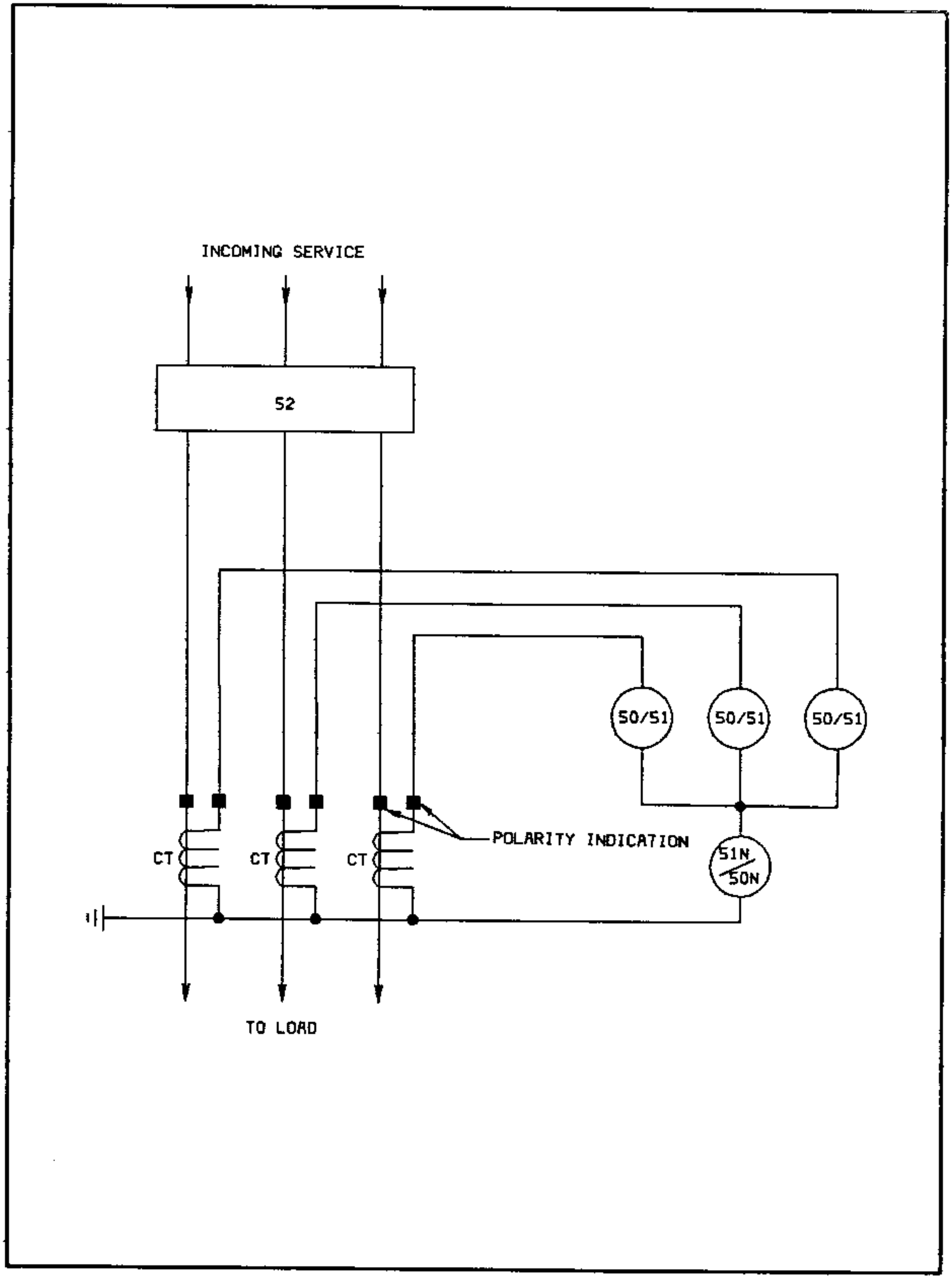


Figure 2
Nondirectional Overcurrent Relaying

4.11.2.1 Directional Operation. Directional relays have three principal components: a directional unit, an induction disk overcurrent unit, and an instantaneous unit. The latter shall be of the cup or cylinder type because a better line coverage is provided for instantaneous tripping. As long as the directional unit contacts are open, the overcurrent units can develop no torque. The directional unit contacts must close in the tripping direction before either the instantaneous overcurrent units or the time-delay overcurrent units can operate (see Figure 3).

4.11.2.2 Directional Voltage. The directional unit contacts are correctly operated by voltage taken from double secondary bus potential transformers, as shown in Figure 3. Delta polarization voltage for the phase relays comes from the 66-volt tap of wye-connected secondaries. If only one secondary winding is available, three auxiliary transformers shall be connected wye-broken delta for zero sequence potential.

4.12 Protection of Power Transformers. Protection considerations are dependent upon whether the transformer supplies utilization or distribution voltages.

4.12.1 Utilization Voltage Transformers. Most transformers will be of the secondary-unit substation type and usually 1,000 kVA or less in size. These will normally be protected with fuses. However; where primary circuit breakers (medium voltage) are warranted, then the requirements for distribution voltage transformers shall apply.

4.12.2 Distribution Voltage Transformers. The necessary circuit switching and protection for transformers with high- or medium-voltage primaries and medium-voltage secondaries can be accomplished either by a circuit breaker or by a switch and fuse combination. The switch and fuse combination is the most economical, but fuse current capabilities may be less than those for the more expensive circuit breaker. Therefore, in those cases where the continuous current rating necessary is greater than that available for fuses or where the interrupting duty required is more than that advised for power fuses in Table 2, the circuit breakers must be provided. Even when fuse protection is adequate, the use of circuit breakers shall be considered for primary protection of transformers of 5,000 and 7,500 kVA capacity. Circuit breakers are required for transformers of 10,000 kVA and larger in size. Circuit breakers may also be necessary where there are such requirements as the need for automatic switching or for installation in a network system. Judge each installation on its own and take into consideration local practice, importance of the load, and balancing costs against the added reliability of the system. When using circuit breakers for remote or automatic switching, provide a local lockout switch.

4.12.3 Protection of Transformer Internal Faults. Protection can be accomplished by use of one or more of the following methods described in paras. 4.12.3.1 through 4.12.3.5.

4.12.3.1 Fuses. Power fuses on the primary side.

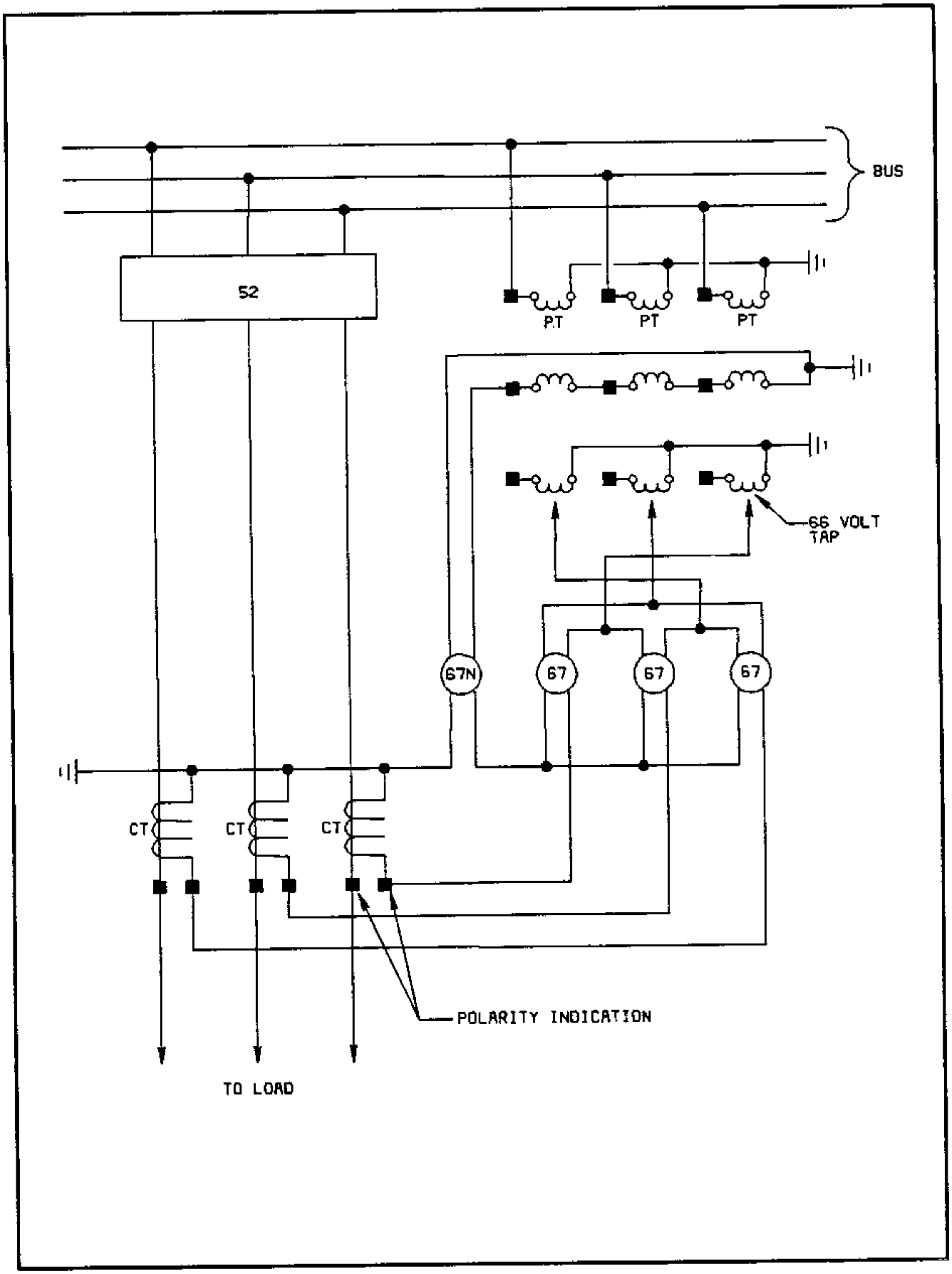


Figure 3
Directional Overcurrent Relaying

4.12.3.2 Temperature. Winding-top oil-temperature (49) relays are used either to sound an alarm in attended stations or to disconnect the primary and secondary circuit breaker (or where there is no primary circuit breaker to disconnect the secondary circuit breaker) in unattended stations. These devices shall not be provided for transformers of 2,500 kVA and smaller transformers protected by power fuses, unless forced-air cooling is provided. For larger transformers without forced-air cooling, use shall be justified by other protective devices available and operating conditions, such as loading and ambient temperature.

4.12.3.3 Pressure. Fault- (sudden) pressure (63) relays for hermetically sealed transformers are used to provide either an alarm or tripping device as described in para. 4.4.3.2. They shall be provided for transformers of 10,000 kVA and larger and where justification may be provided for transformers of 5,000 and 7,500 kVA capacity. An advantage in providing sensitive fault-pressure relays is that other relaying, such as differential protection, need not be nearly as sensitive and that undesired tripping on magnetizing-circuit inrush is minimized. False tripping is sometimes a problem with these relays, so facilities which cannot afford to be shut down and are unattended shall have remote alarms at an attended point. The Buchholz type of gas accumulator fault detection consists of two float devices to trap evolved gas. One float chamber collects gas bubbles given off gradually and sounds an alarm; the other operates by a rush of oil through piping which closes the contacts and disconnects the transformer. This device, used primarily in Europe, has been used little in the United States because of claims that this device is for the sole protection of transformers. The diaphragm and float device contains a float chamber to sound an alarm on the accumulation of gases. The device has had moderate application in the United States and Canada. However, adequate detection use was made in Canada by four major transformer users, and thus damage was prevented beyond the incipient stage. Objections to this relay have been the special construction requirements, maintenance, and the expense of untanking and inspecting after a relay indication. (These have not proven to be true.) Sometimes, a chemical analysis is made and accumulated gas is tested for combustability. Also, considerable weight is given to the length of time between alarms. The United States is believed to have underestimated the use of gas accumulation relays. These relays are not limited to conservation-type transformers, but it is hoped that this principle will be applied to other types of transformers.

4.12.3.4 Differential Protection. Differential protection requires that each transformer winding be provided with a circuit breaker, and the operation trips all circuit breakers. In general, it shall be provided for transformers of 5,000 kVA and larger.

4.12.3.5 Instrumentation. Minimum instrumentation for transformers dependent on voltage level and size is given in Table 6.

4.12.4 Requirements for Differential Relays. Differential relaying shall be provided where it is warranted by transformer size or for other reasons.

Table 6
Minimum Instrumentation for Transformers

Devices	Low-Voltage secondary		Medium-Voltage secondary											
	Unit Capacity													
	500 kVA and below	500 kVA and above[1]	2,500 kVA and below;				3,750 kVA to 7,500 kVA				10,000 kVA and above			
	Circuits													
	Secondary main	Secondary main	Incoming line[1]	Secondary main	Feeder	Parallel sources	Incoming line[2]	Secondary main	Feeder	Parallel sources	Incoming line	Secondary main	Feeder	Parallel sources
Relays														
Synchronism check (25)[3]........	None required	None required				x				x				x
Overcurrent, phase & ground.. (51)(51N)			x	x	x	x	x	x	x	x	x	x	x	x
Directional over-current....(67)(67N)						x				x				x
Reclosing..(79)....				x				x					x	
Differential current....(87)...							x				x			
Meters														
Ammeter............		x	x	x			x	x	x		x	x	x	
Voltmeter..........		x	x	x			x	x			x	x		
Frequency meter....						x				x				x
Wattmeter..........	x	x		x				x				x	x	
Varmeter...........				x				x				x		
Watthour meter.....		x	x				x				x			
Miscellaneous														
Synchroscope.......	–	–				x				x				x

[1] For transformers 2,000 kVA and above, provide instrumentation as shown for medium-voltage secondaries.
[2] Relays apply only when circuit breakers are provided.
[3] Numbers in parentheses are ANSI device numbers.
[4] Refer to para. 2.2.2, Reclosers and Sectionalizers, of this handbook.

4.12.4.1 Harmonic-Restraint Relays. High-speed harmonic-restraint differential (87) relays provide the best protection possible, but they are complicated devices and require frequent maintenance and testing.

4.12.4.2 Time-Overcurrent Relays. Very-inverse time-overcurrent (51) relays can also provide differential protection, as shown in Figure 4, and can provide adequate protection for most locations. For overcurrent relays, approximate settings shall be with the overcurrent element set to about 40 percent of rated current, with a time dial set at 0.5 to 1.0 and instantaneous trip set at 2-1/2 to 3 times rated current. Installation checks must be made to ensure nonoperation on inrush. This is done by energizing with the secondary open for about 10 times in succession, visually observing relay action, and readjusting the settings when necessary. However, plain overcurrent relays are very poor differential relays, and it takes much engineering time to determine a setting which will not operate for through faults.

4.12.5 Additional Requirements for Differential Relaying

4.12.5.1 Grounding. Differential relaying circuits shall be grounded at one point only.

4.12.5.2 Parallel Transformers. Where a differentially protected transformer is operated in parallel with other transformers, differential relaying shall be provided for all transformers.

4.12.5.3 Three-Winding Transformers. Apply the same rules as for two-winding transformers.

4.12.5.4 Transformers with Load Tap Changing Features. Additional requirements apply as follows:

a) Differential relay operation shall cover the maximum range of taps.

b) Current transformer ratios shall be chosen for the maximum emergency current rating of the transformer; that is, the lowest voltage tap when carrying NEMA overload voltage.

4.12.5.5 Current Transformers. Current transformers used in differential protection schemes shall not be used for any other purpose than for differential relaying. Special care shall be exercised in the determination of the correct current transformer connection to prevent unbalanced currents from flowing in the differential relaying circuits.

a) Characteristics. Phase error, ratio error, and saturation characteristics of current transformers for differential relaying shall be matched as far as practicable.

b) Corrective Autotransformer and Relay Taps. When adequate balance cannot be obtained with standard current transformers, correcting autotransformers and relay taps is necessary even though such a system reduces the sensitivity of the scheme.

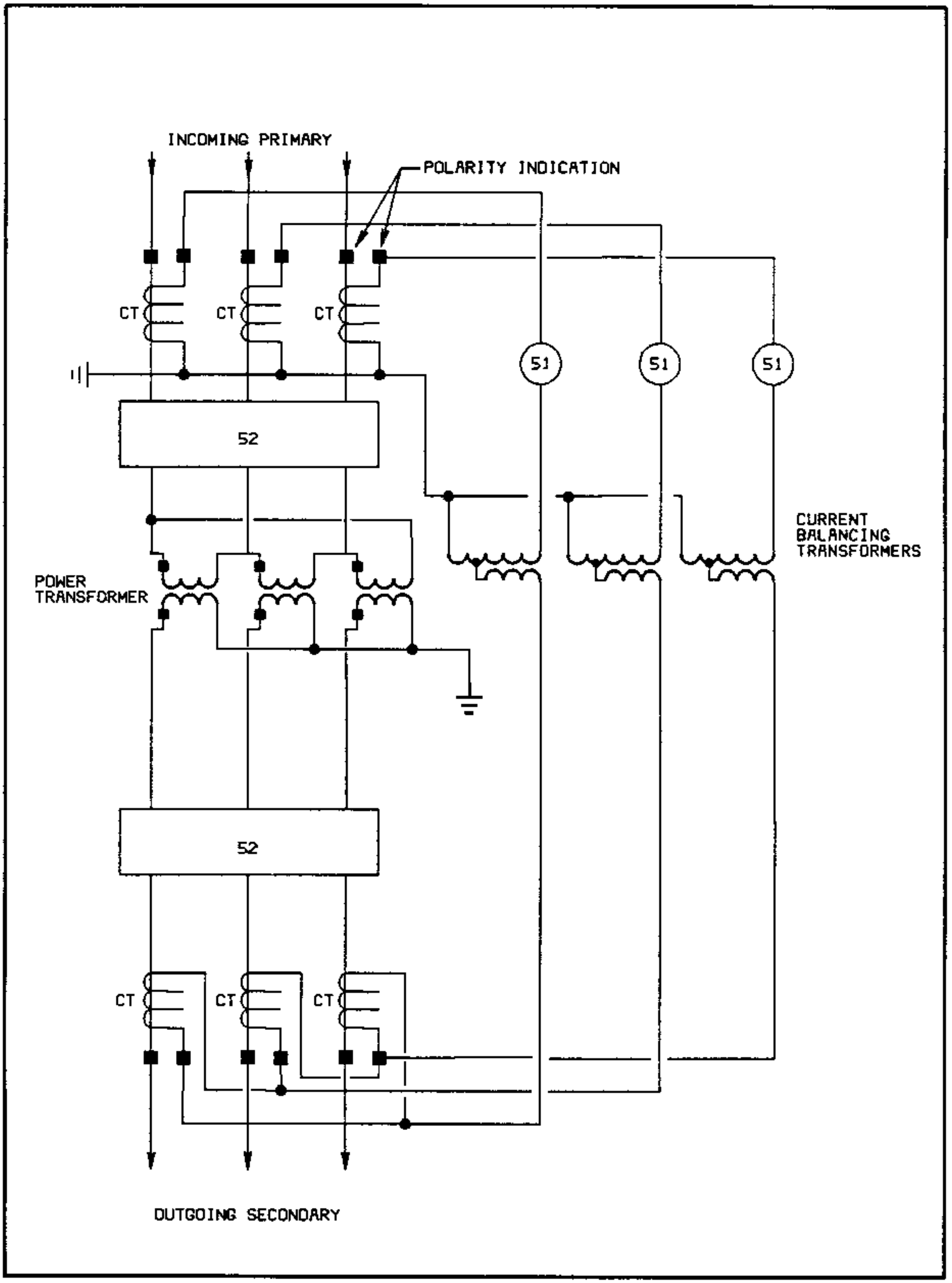


Figure 4
Transformer Time-Overcurrent Differential Relaying

c) Current Transformer Ratios. Current transformer ratios shall be based on the kVA rating of the largest winding and on the voltage rating of each winding.

d) Current Transformer Connections. Current transformers for delta-connected transformer windings shall be wye connected. Current transformers for wye-connected transformer windings shall be delta connected.

4.12.6 Miscellaneous Requirements. All transformers shall meet the installation requirements of NFPA-70, and in addition, oil-immersed units shall be separated from buildings and provided with fire exposure protection as covered in MIL-HDBK-1008, Fire Protection for Facilities Engineering, Design, and Construction. Transformers provided with forced-air cooling shall have necessary interlocks and alarm contacts so that all transformer auxiliaries (fans, pumps, and similar items) start and shut down correctly and send a trouble signal to a designated location.

4.13 Protection of AC Machines. Relay protection of rotating machines, such as motors or generators, is generally provided only for medium-voltage units (refer to Criteria Manuals on Mechanical Engineering).

4.13.1 Generators. The minimum instrumentation provided for generators shall not be less than that indicated in Table 7. Where load shedding is required, frequency (81) relays shall be provided with on-off selector switches to permit choice of feeders dropped, which is dependent upon operating conditions. The relays operate on drop of system speed, which follows loss of generation, to save the system from collapse. This is not the same as load dropping, which is done to limit loads. Undervoltage (27) relays, which might be appropriate for load dropping, cannot be used for load shedding because generator regulators will hold the voltage up.

4.13.2 Motors. Protection of medium-voltage motors will depend upon the use, size, and type of motor and whether the motor is in an attended or unattended location. The manufacturers' recommendations shall also be taken into account. Standard relaying is available, and the value of additional protection must be evaluated on a case-by-case basis.

4.14 Protection of Switchgear. Protection of switchgear and open substation busing shall use an opposed-voltage differential or a circulating current differential system, but only when the system serves loads large enough to be considered of sufficient importance to justify this extra protection. IEEE surveys indicate a very low failure rate for bus, with inadequate maintenance providing the greatest contribution to failures. There is also a danger that more problems will result from false tripping of relays than from bus failures, especially if the relays are inadequately maintained. Because of system cost and complexities, differential relaying shall be used only to protect extremely important buses where the short-circuit duty is excessive.

4.14.1 General Considerations in Bus Differential Relaying. Current transformers used in differential protection schemes shall not be used for any other purpose.

Table 7

Minimum Instrumentation for Medium-Voltage Generators

Devices	Generator Size (WA)		
	up to 500[2]	501 to 12,500	12,500 and up
Relays			
Device 51V, backup overcurrent relay, voltage restraint, or voltage-controlled type	1	3	3
Device 51G, backup ground time-overcurrent relay	1	1	1
Device 32, reverse power relay, antimotoring protection	1[1]		1
Device 40, reverse VAR relay, loss of field protection	l[1]		
Device 87 instantaneous overcurrent relays providing self-balance-type differential protection	3[1]		
Device 87, differential relays, fixed or variable-percentage type, either standard speed or high speed, or the self-balance-type whenever applicable		3	
Device 40, impedance relay, offset-mho type for loss of field protection, single-element type		1	
Device 46, negative- base-sequence overcurrent relay		1[3]	1
Device 87, differential relays, high-speed,variable-percentage type			3
Device 87G, Ground differential relay, directional product type			1
Device 40, impedance relay, offset-mho type for loss of field protection, two-element type is recommended			1
Device 49, temperature relay to monitor stator winding			1
Device 64F, generator field ground relay, applicable only on machines having field supply slip rings			1
Device 60, voltage balance relay			1
Metering			
AC ammeter with switch	1	1	1
DC ammeter (field)		1	1
AC voltmeter with switch	1	1	1
DC voltmeter (field)		1	1
Frequency meter	1	1	1
Wattmeter		1	1
Varmeter		1	1
Watt-hour meter		1	1
Power factor meter		1	1
Synchroscope panel with synchroscope, bus AC voltmeter, bus frequency meter, generator AC voltmeter, and generator frequency meter	1[4]	1[4]	1[4]

1 Additional protection that shall be considered for multiple machines on an isolated system.

2 For generators having excitation systems that do not have the ability to sustain the short-circuit current, even the basic minimum recommendations will not apply. These machines will typically be single isolated units having very small kVA ratings.

3 In the larger machine ratings, and especially those operating in parallel with a utility company supply, this additional relay is recommended.

4 A synchroscope panel is required whenever the generator will be manually synchronized to another source. Also, a synchroscope switch must be provided for each generator.

4.14.1.1 Ratios and Types. All current transformers for bus differential relaying shall be of the same ratio range and type. Multiratio current transformers must be operated on their full windings. Tap connections cannot be used.

4.14.1.2 Sectionalizing. Buses shall be sectionalized to prevent dropping all load upon a bus failure. At least two sections shall be provided. Sections normally have about four to six feeders supplied from one differential zone. Bus tie breakers are used for sectionalizing, with protective zones at the current transformers provided on each side of the breaker, so overlapping of bus differential zones can be established.

4.14.1.3 Installation. Bus differential current transformers shall be installed on the line side of all circuit breakers, except those for the bus tie.

4.14.1.4 Maintenance. Special arrangement shall be made for frequent maintenance and testing of the installation with the bus in service. The risk of accidental tripping increases in direct proportion to poor maintenance; where accidental tripping happens often, operating personnel usually disconnect or reset relays so that the bus differential system has been essentially eliminated.

4.14.2 Forms of Bus Differential Relaying.

4.14.2.1 Circulating-Current Differential System Using a High-Impedance Relay. The circulating-current differential system using a high-impedance relay shown in Figure 5 is the type of relay used is a high-impedance relay designed to provide instantaneous bus differential protection. This relay consists of an instantaneous overvoltage cylinder unit, a voltage-limiting suppressor, an adjustable tuned circuit, and an instantaneous current unit. Considerable care is needed in investigating the current transformers and circuits in order to determine the correct settings of the trip elements. Properly applied, these relays are largely immune from the effects of current transformer saturation.

4.14.2.2 Circulating-Current Differential System Using Time-Overcurrent Relays. The application of the circulating-current differential system using time-overcurrent relays is limited to substations where both short-circuit currents and X/R ratio are low. This system does not provide high-speed relaying; however, it can be used economically by avoiding saturation in the current transformers. The circuitry is the same as shown in Figure 5, except a time-overcurrent relay is substituted for the voltage relay.

4.14.2.3 Opposed-Voltage Differential System. The opposed-voltage differential system requires the use of air-core current transformers called "Linear Couplers (LC)." These LCs are mutual reactors wound on nonmagnetic toroidal cores which produce a small voltage and are used instead of the usual current transformers. All secondary windings shall be connected in series so that, when no fault is on the bus, the resultant voltage will be zero. The risk of operation due to saturation of current transformer cores will be eliminated by this scheme (see Figure 6). LCs and LC relays offer a simple and reliable form of bus protection. LCs are normally used only for outdoor open-bus differential protection because of their size. It is not economically feasible to use LCs with switchgear, and they are not widely manufactured.

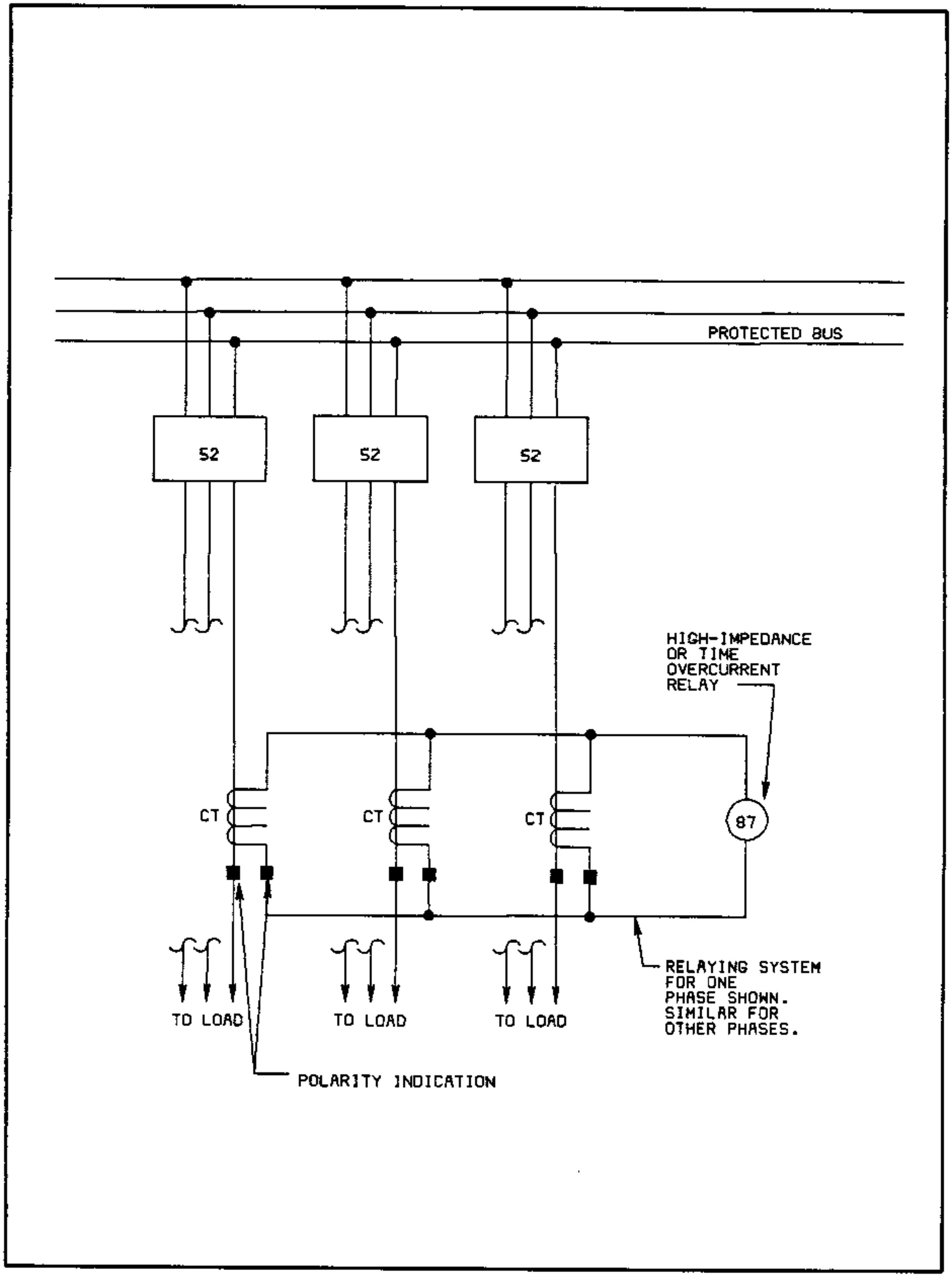


Figure 5
Circulating-Current Differential Relaying

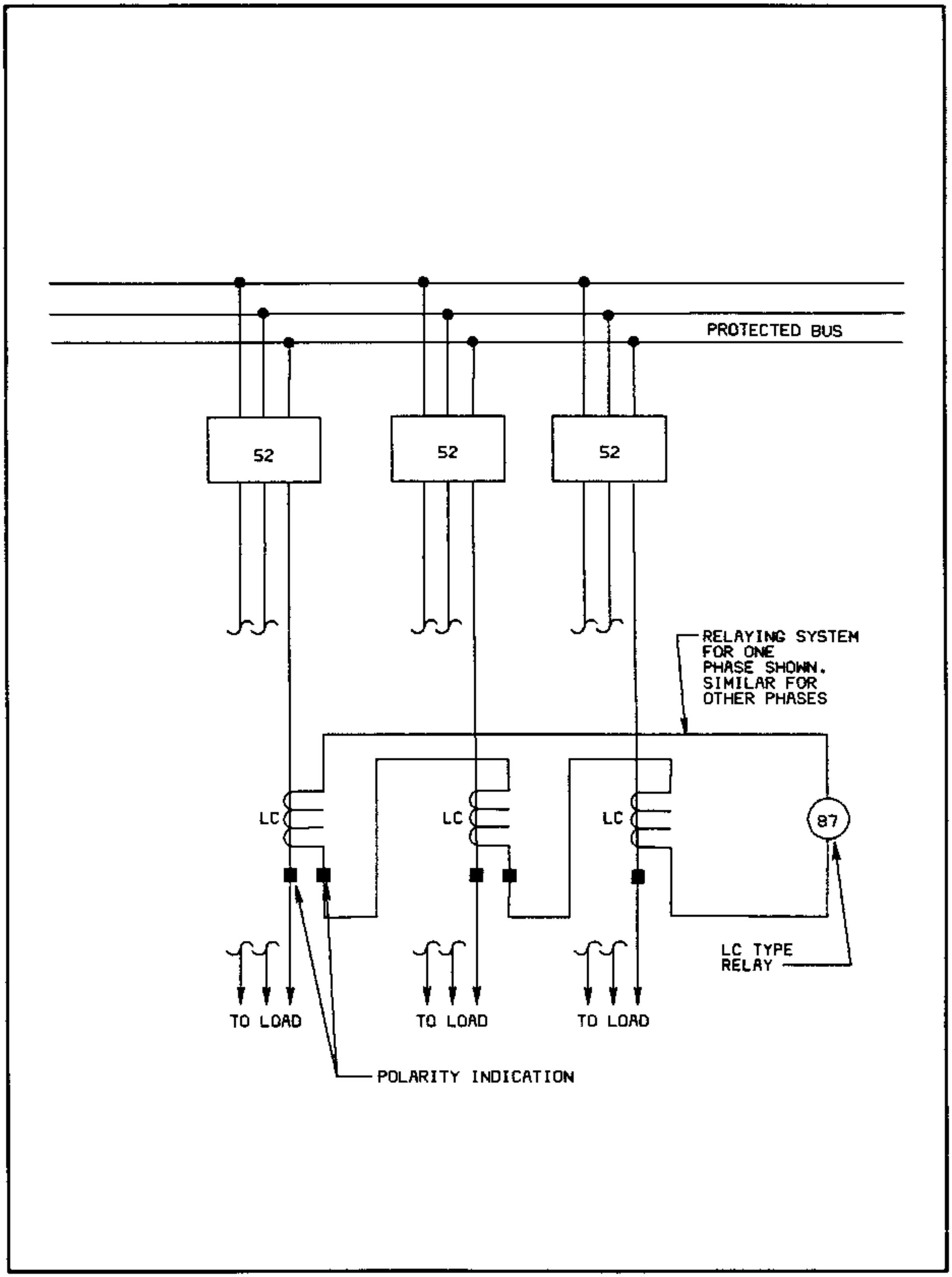


Figure 6
Opposed-Voltage Differential Relaying

4.14.3 Ground Detectors Operating an Alarm. Ground detectors that trigger an alarm shall be provided on ungrounded delta systems. Wye systems are protected by the use of ground relays.

4.14.4 Unacceptable Systems. Some forms of switchgear protection are considered to be too complicated for use in new installations. Where extensions or modifications to existing systems occur, the following protective systems shall be carefully evaluated before incorporating them into the changes:

a) Circulating-current percentage differential system,
b) Frame leakage ground-fault relaying, and
c) Directional comparison system of bus protection.

4.14.5 Cascading. Cascading is not recommended and shall be applied only as a temporary measure when all other efforts to limit fault currents have been exhausted. Cascading shall be used only when approved by NAVFACENGCOM Headquarters and under the following conditions:

4.14.5.1 Application Limitations. Cascading of circuit breakers is allowable only for existing installations where breakers are no longer able to interrupt the increased short-circuit currents or where it is permissible to interrupt service to a number of loads when a fault occurs on but one of a group.

4.14.5.2 Operating Characteristics. The switchgear must be capable of withstanding, both mechanically and thermally, the largest available fault currents. Each breaker's operating characteristics must be so coordinated that no breaker will open against a fault in excess of its rating.

4.15 Relaying of Subtransmission Lines. Relaying of subtransmission lines will generally be the same as for distribution lines, except for the need for directional control.

4.15.1 Types of Relays.

4.15.1.1 Directional Relays. Very-inverse directional (67) relays must be used where appreciable fault current can flow in either direction. Relays with cylinder-type instantaneous attachments may provide instantaneous fault clearing for about 75 percent of the line length when maximum fault duty is imposed on the bus. Nondirectional relays (51/50, 51N/50N) with instantaneous attachments can be used where backfeed to the bus is less than 25 percent of the minimum fault current at the far end of the protected line section. Plunger-type instantaneous attachments can provide instantaneous tripping for about 60 percent of the line. In either case, the reach (length of line covered) of the instantaneous trip will be reduced if the short-circuit duty at the bus is decreased by a reduction in generating capacity.

4.15.1.2 Pilot-Wire Relays. Pilot-wire (85) relays shall be avoided unless there is no satisfactory alternative (see Figure 7). These systems are very expensive, require some form of backup, are difficult to maintain, and introduce additional operational problems. The major maintenance problem is often the pilot wire itself. Events such as lightning, high winds, cable failures, as well as incorrect installation, cause most of the problems. Load is not a criterion for selecting a pilot-wire protection system. Pilot-wire relays are used in the absence of other means to get the required high-speed clearing and selectivity; such relays may be necessary in the following types of lines:

a) To reduce the number of time steps in some sections of a loop circuit.

b) To protect underground cables, because the low impedance of short cable runs does not provide discrimination in fault current levels between source and load ends. Such discrimination is necessary to make time-overcurrent relays effective. However, overcurrent relays (usually directional type) are needed as backup for pilot-wire relays even though their performance is less than that desired.

c) To protect short sections of 69 kV or 115 kV aerial lines which supply naval facilities. Such lines (5 to 10 miles [8 to 16 km]) are usually owned by the local utility company, which provides the necessary protection.

4.15.2 Pilot-Wire System Requirements.

4.15.2.1 Characteristics. Pilot-wire systems are basically different schemes of the opposed-voltage or circulating-current type. Special characteristics are as follows:

a) A relay is provided at each end of the line; usually, only two pilot wires are used.

b) Pilot wires normally are not connected to the actual pilot-wire relays but to insulating transformers that summate the three-phase current.

c) The maximum line length protected in this manner shall not exceed 20 miles (32 km); backup protection is necessary where pilot-wire protection is used.

d) Care shall be exercised in the selection of pilot-wire surge protection. Some pilot-wire systems may not provide reliable performance as a result of the protective measures applied to the circuits to prevent damage to the relays from voltage spikes and similar hazards.

4.15.2.2 Alternate Systems. The cost of providing pilot wires is high. Modifications of the scheme may include the use of rented telephone company lines, actual power conductors (carrier current), or fiber optics.

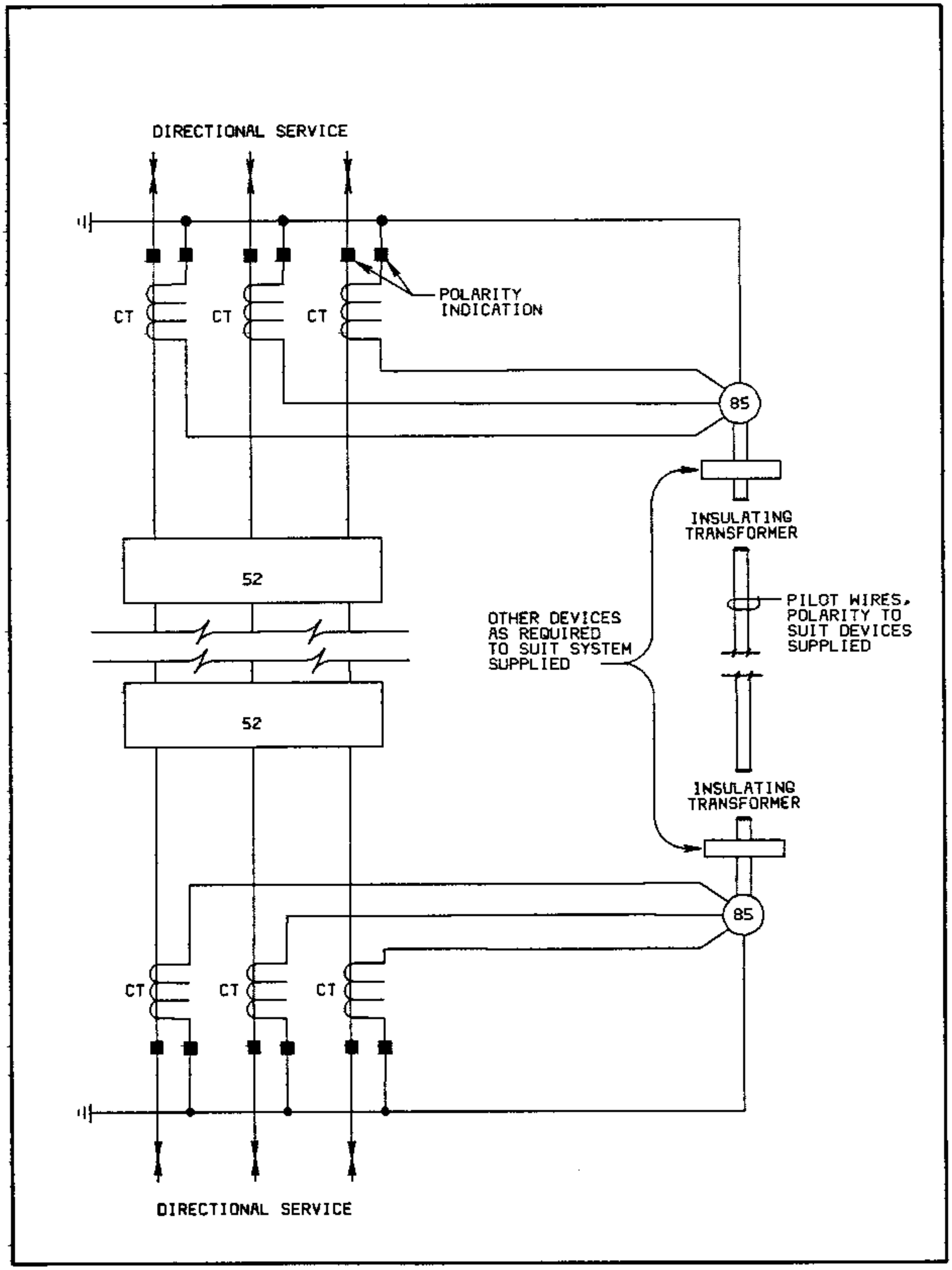


Figure 7
Pilot-Wire Relaying

Section 5: ELECTRONIC POWER MONITORING SYSTEM AND SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM

5.1 Introduction. Power monitoring systems are used to monitor electrical distribution systems or portions of distribution systems. Power monitoring is done by installing individual meters such as ammeter, voltmeter, watt-hour meter, etc., on the desired electrical metering points or on the power equipment being monitored. State-of-the-art electronic power monitors have multiple metering and status monitoring functions which replaces the need of installing individual meters and monitors. Use power monitors instead of individual meters as standard power metering devices. The power monitors can be fully interfaced with a computer. When monitors are interfaced with a computer equipped with a power monitoring software historical, as well as instant information of the status of the power distribution system can be obtained at operator request.

A Supervisory Control and Data Acquisition (SCADA) system is a fully centralized system which is used for supervisory control of protective and switching devices, including generator operation, as well as providing power monitoring system functions.

The power monitoring system and the SCADA system described in this section relate to 15 kV medium and 600 V low voltage power systems. Both systems are microprocessor based.

5.2 Power Monitoring Systems. Power monitoring systems are used for metering and power device/system status monitoring purposes as described in paragraph 5.2.1.

5.2.1 Monitoring Functions. Generally, a power monitor is capable of monitoring a part or all of the following:

a) Phase currents
b) Line-to-line voltages
c) Line-to-neutral voltages
d) 3-phase real power
e) 3-phase reactive power
f) Average demand real power
h) Peak demand power
i) Predicted demand real power
j) Average demand currents
k) Peak demand current
l) Power accumulated
m) Reactive power accumulated
n) Power factor
o) Frequency
p) Temperature
q) Device operations and their trip status
r) Recording monitored data

5.2.2 Components of Power Monitoring Systems. Components of fully centralized monitoring systems include power circuit monitors, circuit monitor display, master station with system software, communication links, system network interface controller and line printer. A master station is a centralized display terminal (usually a personal computer terminal) capable of interfacing with all circuit monitors through network interface.

5.2.3 Power Monitoring System Types. Power Monitoring Systems are categorized as one of the following types:

a) Decentralized Power Monitoring System;
b) Group Centralized Power Monitoring System; or,
c) Master Centralized Power Monitoring System.

5.2.3.1 Decentralized Power Monitoring System. Use a decentralized power monitoring system to monitor a dedicated individual power device or a power line, one monitor for one device. It is comprised of a power monitor connected directly to a device to be monitored. It is the simplest type of power monitoring system and is mainly used as a multi-metering device and/or as a breaker trip status monitor.

5.2.3.2 Group Centralized Power Monitoring System. The group centralized power monitoring system is equipped with a circuit monitor capable of monitoring multiple devices or other decentralized power monitors. It is comprised of a power monitor interconnected to different individual devices including metering monitors in a loop configuration. Metering and/or circuit breaker trip or started status information can be obtained from the display at the monitor or the information can be relayed to a computer terminal for display. The computer terminal is specially useful when remote monitoring is required. With the computer terminal as an option, this type of monitoring system is suitable for use in a large scale integrated switchgear, switchboards, and motor control center assemblies in a group configuration.

5.2.3.3 Master Centralized Power Monitoring System. For a large scale facility monitoring, when a centralized system display terminal is derived for monitoring purposes, a master centralized power monitoring system can be used by interconnecting all monitors in a facility, including decentralized and/or group centralized system, thus providing master monitoring at a centralized terminal. This system is recommended for a large power facility system requiring a central monitoring of more than 60 devices.

5.3 SCADA System. A SCADA system is capable of power monitoring as indicated in paragraph 5.2 and also, of operating power system devices, mainly switching or motor starting, individually or sequentially, in automatic mode or manually via keyboard. Device operation is carried out by means of sending electrical signals, which make the operating mechanism of the device operate. Automatic operations of selective devices are performed by preprogrammed settings via a master station. A manual operation, though not recommended, is carried out by commands at the master station at an instant when an operation is desired. The system monitoring and controls are run by a system software/hardware package included in the SCADA system. SCADA systems are recommended in large facilities requiring critical power reliability, facility-wide power system monitoring and automated power system operation.

5.3.1 Control Functions. Operating control functions may include a part or all of the following:

a) Operation of breakers and switches
b) Transfer switches and/or generator start-up operations
c) Load-shedding and sequencing operations
d) Power factor correction via capacitor switching
e) System diagnostics

5.3.2 SCADA System Components. In general, SCADA systems are comprised of the following components: circuit monitors, master station with system software and network interface controller, line printer, and system links.

5.4 Surge Protections. Protect all equipment against power line surges as recommended by IEEE C62.41 and against surges induced on communication signal circuits. Protect computer equipment with surge protectors. Do not use fuses for surge protection.

5.5 Backup Power Supply. Provide 15 to 30 minute battery backup for both centralized power monitoring and SCADA systems.

5.6 System Configuration. Configuration of a monitoring and control system should be such that future addition or modification will be at a minimum cost. Usually, system components of various manufacturers do not interface with one another. Make sure to design new systems incorporating components capable of interfacing and future expansion. When expanding or modifying an existing system, make sure that new components are fully compatible with existing system components. Specify installation and operational testing of centralized systems shall be under supervision of a technical representative of the manufacturer supplying the monitoring or the SCADA system.

Appendix A
FAULT CURRENT CALCULATIONS BY THE SIMPLIFIED GRAPHIC METHOD

Section 1: SCOPE

A1.1 Determination. To determine the interrupting requirements of low-voltage circuit breakers, it is necessary to establish the fault current available at the point where the circuit breaker is to be located. A short-circuit diagram (see Figure A-1) shows the factors considered in formulating the fault current.

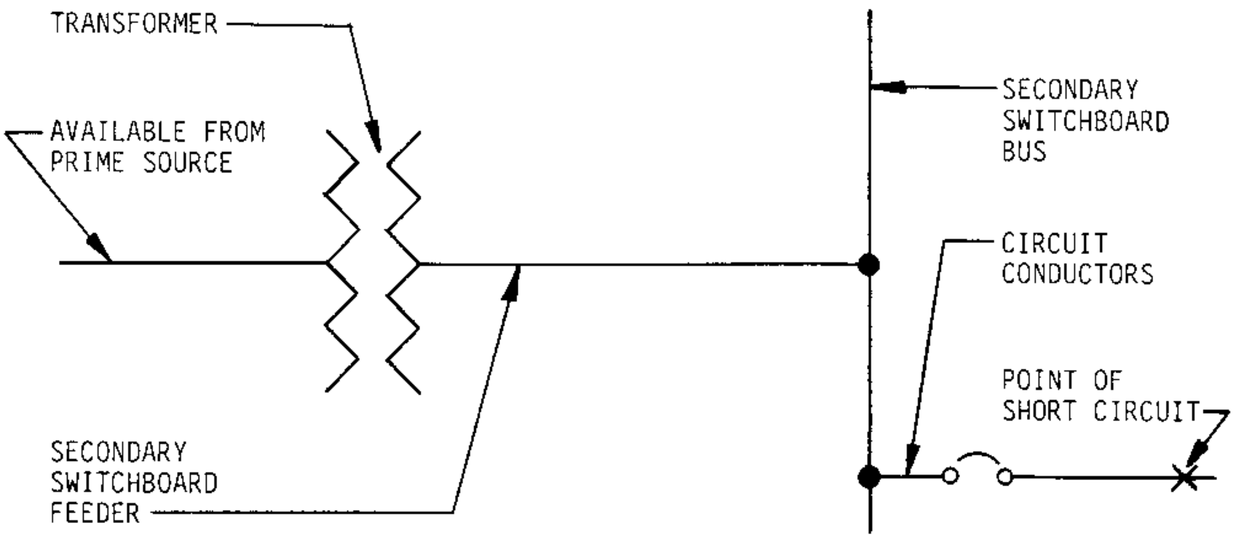


Figure A-1
Short-Circuit Diagram

A1.2 Energy Available from Prime Source. This is the available fault energy which can be delivered by the prime source to the primary side of the transformer. Where an actual value is not available, assume the prime source to be infinite.

A1.3 Transformer kVA Rating. Transformer kVA ratings and percent impedance voltage have an effect on the available fault energy.

A1.4 Circuit Voltage. Low-voltage distribution system of 480Y/277 volts or 208Y/120 volts is generally used.

A1.5 Motor Contribution. Motor contributions do have an effect, but for most cases, short-circuit contributions from any motor are considered to be offset by the impedance of circuit breakers, feeder connection, and other such contributions which are rarely included in calculations unless the motor load is greater than 25 percent of the total load.

A1.6 Feeder Conductors. The conductor size will also determine the short-circuit contribution at the fault point, depending upon its per-unit reactance.

A1.7 Graphs. A simplified graphic method has been developed to determine the fault currents available for common applications at various distances from the transformers. It is sufficiently accurate for most conditions. Figures A-2 through A-4 are based on standard transformer kVA ratings and impedance values and on conductor sizes most commonly used. Two charts are used: one to determine reactance and one to determine fault current.

Section 2: HOW TO USE CHARTS

To use the charts shown in Figures A-2 through A-4, perform the following steps:

Step 1. Obtain the following data: in paras. A2.1.1 through A2.1.3.

a) Transformer kVA rating, percent impedance, and primary and secondary voltages.

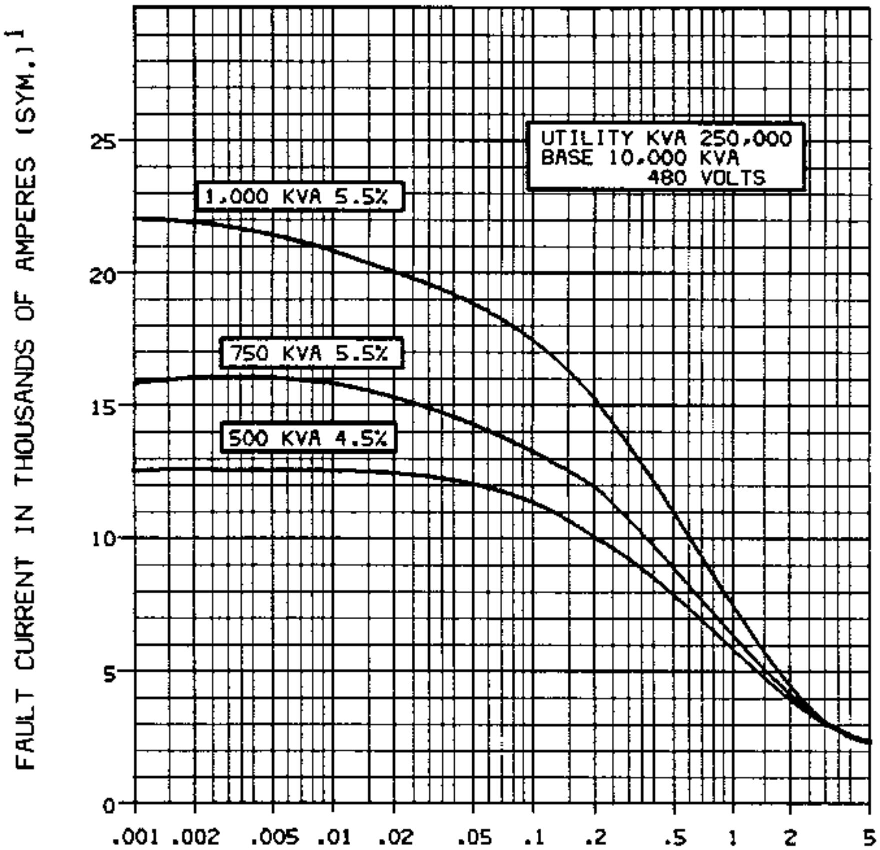
b) Secondary switchboard feeder length and size.

c) Circuit conductor feeder length and size.

Step Two. Compute the total per-unit feeder reactance from the transformer to the feeder breaker by adding per-unit reactances for items in steps 1.b and c, which are obtained from the reactance determination chart. Per-unit reactances are obtained by entering the chart along the bottom scale. The distance of the applicable feeder is measured in feet (meters). Draw a vertical line up the chart to the point where it intersects the applicable feeder curve; from this point, draw a horizontal line to the left toward the scale along the left side of the chart. The value obtained from the left-hand vertical scale is the per-unit reactances of the feeder.

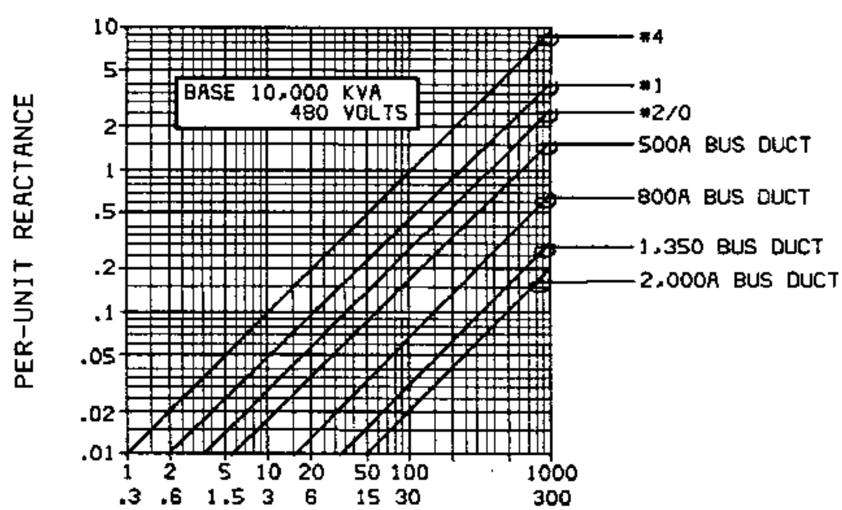
Step Three. Enter the fault current determination chart along the bottom scale with the total per-unit feeder reactance from the transformer to the fault point. Draw a vertical line up the chart to the point where it intersects the applicable transformer curve; from this point, draw a horizontal line to the left toward the scale along the left side of the chart.

Step Four. The value obtained from the left-hand vertical scale is the fault current (in thousands of amperes) available at the fault point.



FAULT CURRENT DETERMINATION CHART[1]

[1] WITHOUT MOTOR CONTRIBUTION



REACTANCE DETERMINATION CHART

Figure A-2
Load Center Supplying 480Y/277 Volts

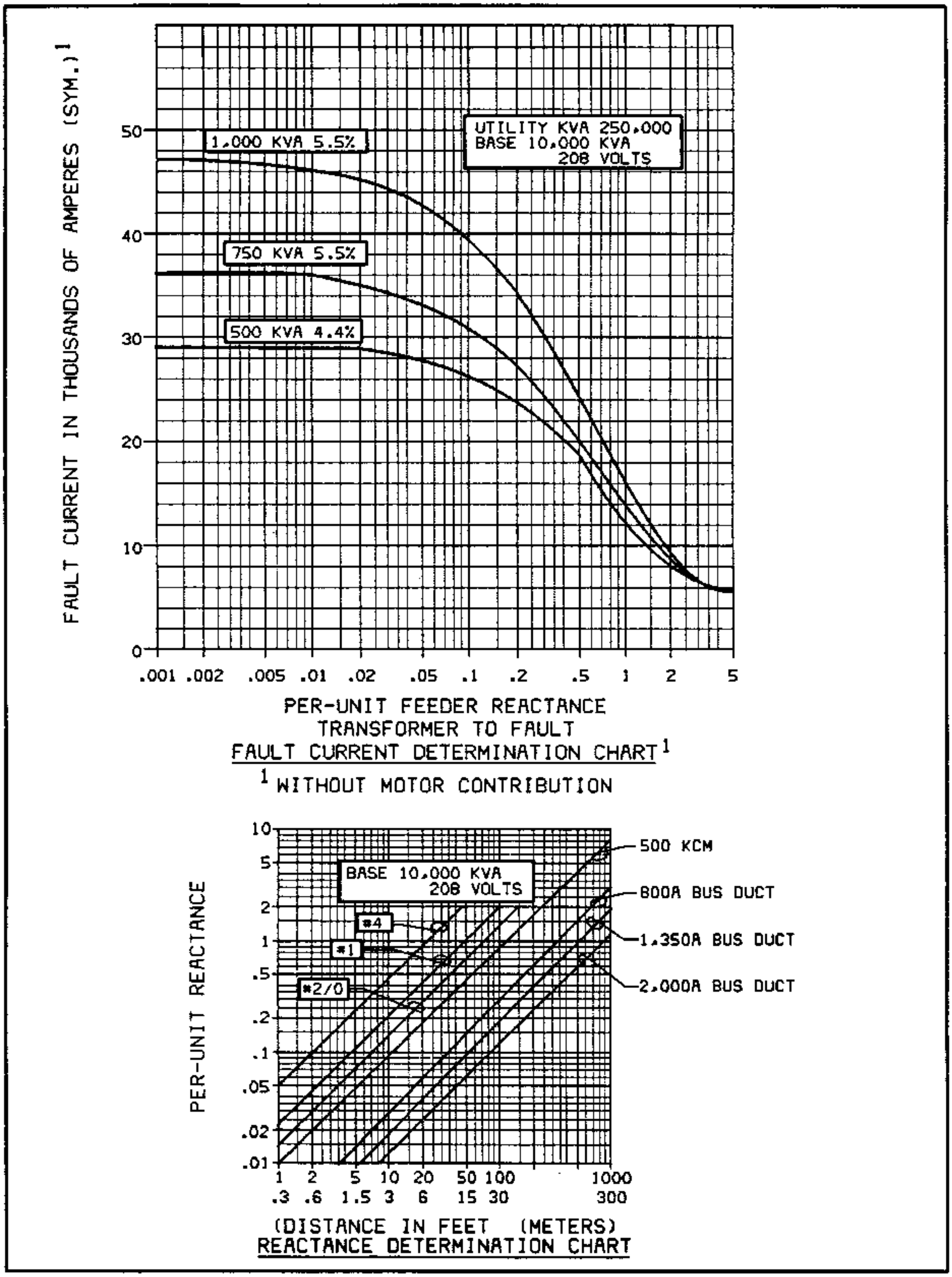
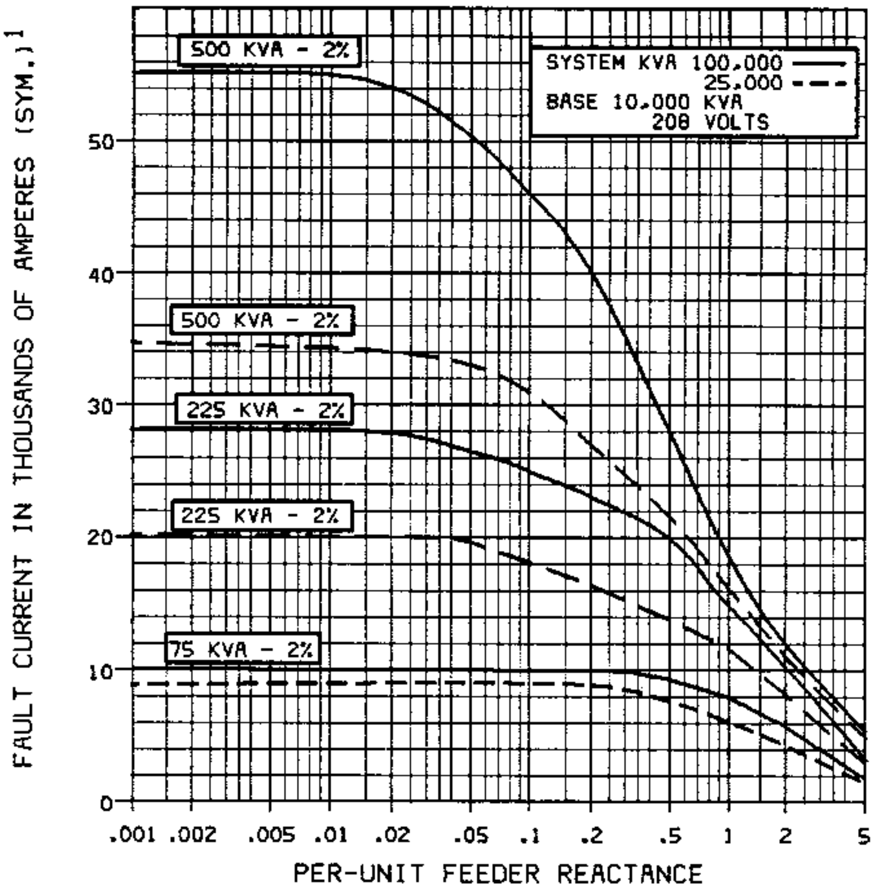
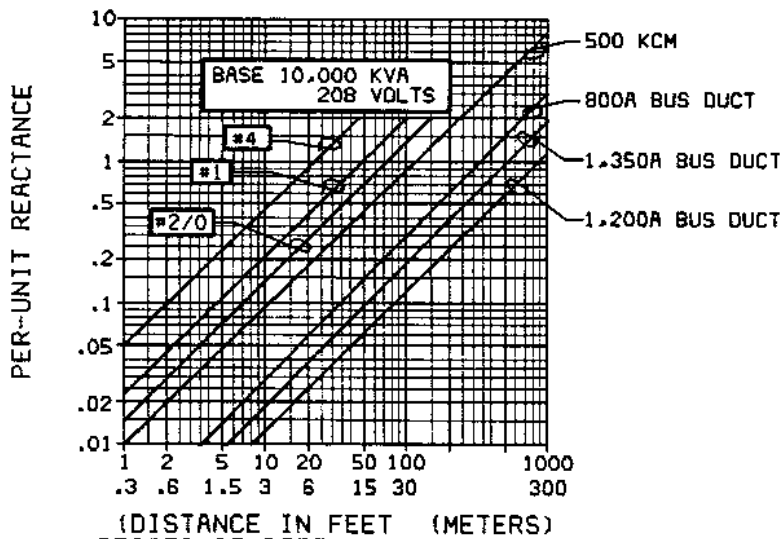


Figure A-3
Load Center Supplying 208Y/120 Volts



FAULT CURRENT DETERMINATION CHART[1]

[1] WITHOUT MOTOR CONTRIBUTION



REACTANCE DETERMINATION CHART

Figure A-4
480-Volt Transformer Supplying 208Y/120 Volts

Appendix B
ANSI STANDARD DEVICE FUNCTION NUMBERS

Device Number	Function
1	Master element
2	Time-delay starting or closing relay
3	Checking or interlocking relay
4	Master contactor
5	Stopping device
6	Starting circuit breaker
7	Anode circuit breaker
8	Control power disconnecting device
9	Reversing device
10	Unit sequence switch
11	Reversed for future application
12	Overspeed device
13	Synchronous-speed device
14	Underspeed device
15	Speed or frequency matching device
16	Reserved for future application
17	Shunting or discharge switch
18	Accelerating or decelerating device
19	Starting-to-running transition contactor
20	Electrically operated valve
21	Distance relay
22	Equalizer circuit breaker
23	Temperature control device
24	Reserved for future application
25	Synchronizing or synchronism-check device
26	Apparatus thermal device
27	Undervoltage relay
28	Flame detector
29	Isolating contactor
30	Annunciator relay
31	Separate excitation device
32	Directional power relay
33	Position switch
34	Master sequence device
35	Brush-operating or slip-ring short-circuiting device
36	Polarity or polarizing voltage device
37	Undercurrent or underpower relay
38	Bearing protective device
39	Mechanical condition monitor
40	Field relay
41	Field circuit breaker
42	Running circuit breaker
43	Manual transfer or selector device
44	Unit sequence starting relay
45	Atmospheric condition monitor
46	Reserve-phase or phase-balance current relay
47	Phase-sequence voltage relay
48	Incomplete sequence relay
49	Machine or transformer thermal relay
50	Instantaneous overcurrent or rate-of-rise relay
51	AC time-overcurrent relay
52	AC circuit breaker
53	Exciter of DC generator relay
54	Reserved for future application
55	Power factor relay
56	Field application relay
57	Short-circuiting or grounding device
58	Rectification failure relay
59	Overvoltage relay
60	Voltage or current balance relay
61	Reserved for future application
62	Time-delay stopping or opening relay
63	Pressure switch
64	Ground detector relay
65	Governor
66	Notching or jogging device
67	AC directional overcurrent relay
68	Blocking relay
69	Permissive control device
70	Rheostat
71	Level Switch

Device Number	Function
72	DC circuit breaker receiver relay
73	Load-resistor contactor
74	Alarm relay
75	Position changing mechanism generator
76	DC overcurrent relay
77	Pulse transmitter
78	Phase-angle measuring or out-of-step protective relay
79	AC reclosing relay
80	Flow switch
81	Frequency relay
82	DC reclosing relay
83	Automatic selective control or transfer relay
84	Operating mechanism
85	Carrier or pilot-wire
86	Locking-out relay
87	Differential protective relay
88	Auxiliary motor or motor
89	Line switch
90	Regulating device
91	Voltage directional relay
92	Voltage and power directional relay
93	Field-changing contactor
94	Tripping or trip-free relay
95	Used only for specific
96	functions in individual cases
97	where none of the assigned
98	numbered functions from 1
99	to 94 are suitable.

Appendix C
INTERNATIONAL SYSTEM OF UNITS (SI) CONVERSION FACTORS

QUANTITY	U.S. CUSTOMARY UNIT	INTERNATIONAL (SI) UNIT	APPROXIMATE CONVERSION
LENGTH	foot(ft)	meter(m)	1 ft = 0.3048 m
	foot(ft)	millimeter(mm)	1 ft = 304.8 mm
	inch(in)	millimeter(mm)	1 in = 25.4 mm
AREA	square yard(yd[2])	square meter(m[2])	1 yd[2] = 0.836 127
	square foot(ft[2])	square meter(m[2])	1 ft[2] = 0.092 903
	square inch(in[2])	square millimeter(mm[2])	1 in[2] = 645.16 mm[2
VOLUME	cubic yard(yd[3])	cubic meter(m[3])	1 yd[3] = 0.764 555
	cubic foot(ft[3])	cubic meter(m[3])	1 ft[3] = 0.028 317
	cubic inch(in[3])	cubic millimeter(mm[3])	1 in[3] = 16,387.1 mm[3]
CAPACITY	gallon(gal)	liter(L)	1 gal = 3.785 41 L
	fluid ounce(fl oz)	milliliter(mL)	1 fl oz = 29.5735 mL
VELOCITY, SPEED	foot per second (ft/s or f.p.s.)	meter per second(m/s)	1 ft/s = 0.3048 m/s
	mile per hour (mile/h or m.p.h.)	kilometer per hour (km/h)	1 mile/h = 1.609 344
ACCELERA-TION	foot per second squared(ft/s[2])	meter per second squared(m/s[2])	1 ft/s[2] = 0.3048 m/s[2
MASS	short ton(2000lb)	metric ton(t) (1000 kg)	1 ton = 0.907 185
	pound(lb)	kilogram(kg)	1 lb = 0.453 592
	ounce(oz)	gram(g)	1 oz = 28.3495 g
DENSITY	ton per cubic yard(ton/yd[3])	metric ton per cubic meter(t/m[3])	1 ton/yd[3] = 1.186 55 t/m
	pound per cubic foot(lb/ft[3])	kilogram per cubic meter(kg/m[3])	1 lb/ft[3] = 16.0185 kg/m
FORCE	ton-force(tonf)	kilonewton(kN)	1 tonf = 8.896 44 k
	kip(1000 lbf)	kilonewton(kN)	1 kip = 4.448 22 k
	pound-force(lbf)	newton(N)	1 lbf = 4.448 22 N
MOMENT OF FORCE	ton-force foot (tonf.ft)	kilonewton meter(kN.m)	1 tonf.ft = 2.711 64 k
TORQUE	pound-force inch(lbf.in)	newton meter(N.m)	1 lbf.in = 0.112 985

QUANTITY	U.S. CUSTOMARY UNIT	INTERNATIONAL (SI) UNIT	APPROXIMATE CONVERSION
PRESSURE, STRESS	ton-force per square inch (tonf/in[2])	megapascal(MPa)	1 tonf/in[2] = 13.7895 MPa
	ton-force per square foot (tonf/ft[2])	kilopascal(kPa)	1 tonf/ft[2] = 95.7605 kPa
	pound-force per square inch (lbf/in[2])	kilopascal(kPa)	1 lbf/in[2] = 6.894 76 kPa
	pound-force per square foot (lbf/ft[2])	pascal(Pa)	1 lbf/ft[2] = 47.8803 Pa
WORK, ENERGY, QUANTITY OF HEAT	kilowatthour(kWh)	megajoule(MJ)	1 kWh = 3.6 MJ
	British thermal unit(Btu)	kilojoule(kJ)	1 Btu = 1.055 06 kJ
	foot-pound-force (ft.lbf)	joule(J)	1 ft.lbf = 1.355 82 J
POWER, HEAT FLOW RATE	horsepower(hp)	kilowatt(kW)	1 hp = 0.745 700 kW
	British thermal unit per hour (Btu/h)	watt(W)	1 Btu/h = 0.293 071 W
	foot pound-force per second (ft.lbf/s)	watt(W)	1 ft.lbf/s = 1.355 82 W
COEFFICIENT OF HEAT TRANSFER (U-value)	Btu per square foot hour degree Fahrenheit (Btu/ft[2] hr. deg. F)	watt per square meter kelvin (W/m[2].K)	1 Btu/ft[2].h. deg. F = 5.678 26 W/m2.K
THERMAL CONDUCTIVITY (K-value)	Btu per foot hour degree Fahrenheit (Btu/ft.hr. deg.)	watt per meter kelvin (W/m.K)	1 Btu/ft.h. deg. F = 1.730 73 W/m.K

AMERICAN WIRE GAGE (AWG) CONVERSION.

AWG	kCM	mmÀ2Ù
20	1.02	0.517
18	1.62	0.823
16	2.58	1.31
14	4.11	2.08
12	6.53	3.31
10	10.4	5.26
8	16.5	8.37
6	26.2	13.3
4	41.7	21.2
2	66.4	33.6
1	83.6	42.4
1/0	105.6	53.5
2/0	133.1	67.4
3/0	167.8	85.0
4/0	211.6	107.0

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21	General Requirements and Test Procedures for Outdoor Apparatus Bushings
24	Standard Electrical Dimensional and Related Requirements for Outdoor Apparatus Bushings
443	Recommended Practice for Design of Reliable Industrial and Commercial Power Systems
519	Guide for Harmonic Control and Reactive Compensation of Static Power Converters
C2-81	National Electric Safety Code

National Electric Manufacturers Association (NEMA), NEMA Standards, 2101 L Street, NW., Washington, DC 20037.

201	Primary Unit Substations
210	Secondary Unit Substations
SG-2	High-Voltage Fuses
SG-5	Power Switchgear Assemblies
SG-13	Automatic Circuit Reclosers and Automatic Line Sectionalizers and Oil-Filled Capacitor Switches for Alternating Current Systems

National Electric Safety Code, C2, available from IEEE/ANSI Publications, Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017.

Westinghouse Electric Corporation, Post Office 1693, Baltimore, MD 21203.

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C62.2	Guide for the Application of Valve-Type Lightning Arresters for AC Systems
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The Art and Science of Protective Relaying, General Electric Engineering Practice Series, C. Russell Mason, John Wiley & Sons, Inc., New York, NY 10036.

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80	Guide for Safety in Substation Grounding
81	Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System
141	Recommended Practice for Electric Power Distribution for Industrial Plants
142	Recommended Practice for Grounding Industrial and Commercial Power Systems
242	Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
399	Recommended Practice for Industrial and Commercial Power System Analysis

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C37.010	Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

C37.011	Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
C37.04	American National Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
C37.13	Low-Voltage AC Power Circuit Breakers Used in Enclosures
C37.2	Standard Electrical Power System Device Function Numbers
C37.20	Switchgard Assemblies Including Metal-Enclosed Bus
C62.41	Guide for Surge Voltages in Low-Voltage AC Power Circuits

Military Handbooks, available from the Standardization Document Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

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MIL-HDBK-1004/1	Preliminary Design Considerations
MIL-HDBK-1004/2	Power Distribution Systems
MIL-HDBK-1008	Fire Protection for Facilities Engineering, Design, and Construction

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NFGS-16262	Automatic Transfer (and Bypass/Isolation) Switches
NFGS-16312	Low-Voltage Switchgear and Secondary Unit Substations
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BU-1	Busways
ICS 6	Enclosures for Industrial Controls and Systems
KS-1	Enclosed Switches
SG-3	Low-Voltage Power Circuit Breakers
SG-4	Alternating-Current High-Voltage Power Circuit Breakers

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489	Molded-Case Circuit Breakers and Circuit Breaker Enclosures
857	Electric Busways and Associated Fittings

Westinghouse Electric Corporation:

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Electrical Transmission and Distribution Reference Book; 777 Penn Center Boulevard, Pittsburgh, PA 15235.

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